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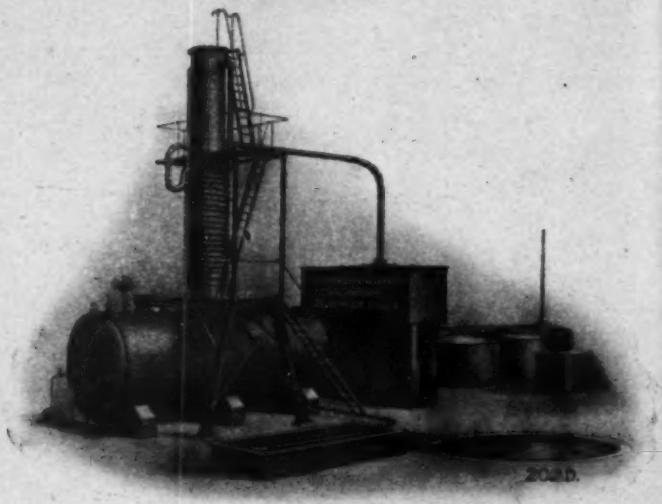

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All members receive these publications free of cost. Additional copies of the Journal are charged at the rate of 7s. 6d. per part, unless otherwise stated, and of any other publication at the price stated on the wrapper.

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English equivalents of foreign weights and measures should be given, and it is suggested that a bibliography of the subject dealt with be appended.

All papers and articles submitted are assumed to be original communications unless otherwise stated, in which case reference to the previous publication should be given.

Members are invited to submit papers to be read at the General Meetings of the Institution, and are specially asked to forward articles for publication in the Journal.

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Bibliography and Abstracts. A bibliography of current literature is published with each issue of the Journal, together with abstracts of the more important articles and patent specifications, this supplement being paged separately to the Transactions. In order to make this section of the maximum value, members are requested to send any matter which may have been inadvertently overlooked to the editor.

Medal for Student Members. A medal and a prize of five guineas will be awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented a paper of outstanding merit during the session.

Advertisements. A number of Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. H. J. Humm, 93 and 94, Chancery Lane, London, W.C. 2. (Telephone No.: Central 8106).

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Library. The Institution's Library may be consulted between the hours of 11 a.m. and 4 p.m. daily. The additions made to the current and standard literature on petroleum and allied substances, since the publication of the last Journal, are :—

From Eugene Coste :—

The Regenerative Coal Gasification System. A Process for the Complete Gasification of Solid Fuels. By Morris W. Travers, D.Sc., etc., and Frank Wm. Clark, M.I.Mech.E.

From the Imperial Mineral Resources Bureau :—

Canadian Official Mining News Letter. The Oil Situation and Prospects in Canada.

From the Publishers (for review) :—

Petroleum Production Methods. By John R. Suman.

Oil Well Drilling Methods. By Victor Ziegler.

The Oil Trusts and Anglo-American Relations. By E. H. Davenport and Sidney Russell Cooke.

From the Institution of Automobile Engineers :—

Proceedings, Vol. XVII., Part II., 1922-23.

From Dean E. Foster :—

"Gaso-graphs," showing the production, consumption and price of gasoline from 1920 to 1923, and "Foster-Baffles," describing products installed in a number of absorption gasoline plants in the Mid-Continent, Rocky Mountain and California Oilfields.

From the Diesel Engine Users' Association :—

Some Considerations affecting the Choice of a Heavy-Oil Engine. By Geoffrey Porter, A.M.Inst.C.E. Also Report of Discussion.

From the American Society for Testing Materials :—

Proceedings, Part I., Vol. 23, Committee Reports, New and Revised Tentative Standards; and Part II., Vol. 23, Technical Papers.

From Eugene Coste :—

The Volcanic Origin of Natural Gas and Petroleum. 2nd Edition. 1905.

From the British Engineering Standards Association :—

Specifications to date.

From the Ministry of Finance, Geological Survey, Egypt :—

Preliminary Geological Report on Saint John's Island (Red Sea). By F. W. Moon, B.E., A.M.I.C.E., F.G.S. With Appendices: (1) A Description of the Peridotites and Associated Rocks, by W. Campbell Smith, M.C., M.A., F.G.S.; (2) A Description of a Davyne-like Mineral and its Pseudomorphs, by L. J. Spencer, M.A., Sc.D., F.G.S.

From the Geological Survey of India :—

Records, Vol. LIV., Part 4, 1923.

From the U.S. Bureau of Mines, Dept. of the Interior :—

Technical Paper 310. Recovery of Gasoline from Uncondensed Still Vapours. By D. B. Dow.

Technical Paper 319. Methods of Decreasing Evaporation Losses of Petroleum. By J. H. Wiggins.

Reports of Investigations, Serial No. 2550, Dec., 1923. The Paraffin Problem in Oil Wells. By R. Van A. Mills.

Reports of Investigations, Serial No. 2547, Nov., 1923. A Floating Roof for Oil Tanks. By Ludwig Schmidt.

From the Imperial Mineral Resources Bureau :—

The Mineral Industry of the British Empire and Foreign Countries. Statistics, 1919-1921. Barium Minerals, Gypsum, Magnesite, Tungsten, Cadmium, Chrome Ore and Chromium, Diamonds, Talc, Monazite, Titanium, Abrasives, Antimony, Asbestos, China Clay, Cobalt, Fluorspar, Fullers' Earth, Mica, Nickel, Phosphates, Salt, Uranium (Radium) Minerals, Bismuth, Graphite, Quicksilver, and Strontium Minerals.

From the Canadian Dept. of Mines, Geological Survey :—

Summary Report, 1922, Parts B. & G.

Third Annual Report of the Scientific and Industrial Research Council of Alberta, 1922, Report No. 8.

Index to Separate Reports, 1906-1910, and Summary Reports, 1905-1916. Compiled by F. J. Nicolas. No. 2000, 1923.

From Henry B. Milner :—

The Oilfields of the Los Angeles Basin, Southern California. By Henry B. Milner, M.A., D.I.C., F.G.S.

The Council would be grateful to members who are authors of books on petroleum or on allied substances if they would kindly present a copy of their works to the Library of the Institution, and for review in the Journal.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. Parnell is on his way back to England.

Mr. A. Rosas has returned to Peru.

Mr. S. H. Chapman has now returned to England.

Mr. G. P. Chaplin has left Burma for England, *via* United States, and hopes to arrive during May.

Dr. Wm. Hope Henderson has returned to London after spending nine months in Ecuador and Peru.

Dr. George Sheppard has returned to England from South America, where he has been carrying out exploration work.

Mr. George E. Stott has left England for Baluchistan and the Punjab, but hopes to return during April.

Mr. Frank B. Lea is sailing for Australia, where he will be engaged for some time on the development of Bitumen compounds for roadmaking and similar purposes.

The Honorary Editor visited the University of Delft, Holland, on February 28, and lectured to the Technologisch Gesellschap on "Some Modern Developments in Refining."

ANNUAL REPORT ON THE PROGRESS OF NAPHTHOLOGY.

It is proposed to devote annually one issue of the Journal to a Report on the Progress of Naphthology during the preceding year. As far as possible it is intended that this Report shall cover the industry in all its aspects, and members having special knowledge of progress in any particular branch are requested to forward such information to the Honorary Editor by the end of March if possible. The Report for 1923 will appear either in the April or June number of the Journal.

PROFESSOR R. R. THOMPSON.

We regret to announce the death of Prof. R. R. Thompson, which took place at Folkestone on January 26th, 1924. Prof. Thompson, who was born in 1884, was educated at Lymington, King's College, London, and the Durham College of Science. Until 1914 he was principally engaged in mining operations, and in that year took a position with the Anglo-Persian Oil Company at Maidan-i-Naftun, where he remained until 1917. Subsequently he became Inspector of Lands and Mines in Trinidad, a post which he relinquished to take up the position of Professor at the University of Birmingham.

Amongst his distinctions were :—Officer of the Order of the British Empire, Bachelor of Science of the University of Durham, a Member of the Institution of Mining Engineers, and an Associate of the Institution of Mining and Metallurgy. Our deepest sympathy is extended to Mrs. Thompson in her great loss.

CURRENT PETROLEUM NOTES.

The receipt of notes of interest for insertion under this heading will be welcomed by the Editor.

GREAT BRITAIN.—The net imports of petroleum and its products into Great Britain during 1923 showed an increase of 8·7 per cent. over the quantity for 1922. From the following table it will be noted that crude petroleum exports increased to the extent of 53·2 per cent., lubricating oils by 19·3 per cent., and those products enumerated in the import schedules as " other sorts " increased by 133·8 per cent. :—

GREAT BRITAIN.

NET IMPORTS (*i.e.*, IMPORTS LESS RE-EXPORTS) OF PETROLEUM AND ITS PRODUCTS FOR THE YEARS 1922 AND 1923.

	Quantity. 1922.	1923.	Increase or decrease in 1923 compared with 1922.
	Imp. Galls.	Imp. Galls.	Per cent.
Crude petroleum	217,084,459	332,616,595	+ 53·2
Lamp oil	148,853,064	140,686,688	— 5·5
Motor spirit	284,543,003	287,626,930	+ 1·1
Other spirit	*	2,649,723	—
Lubricating oil	67,342,671	80,366,529	+ 19·3
Gas oil	69,045,983	68,991,764	— 0·1
Fuel oil	386,565,331	362,342,829	— 6·3
Other sorts	27,557	64,426	+ 133·8
Total	1,173,462,068	1,275,345,484	+ 8·7
	Cwts.	Cwts.	
Paraffin wax	899,243	1,090,363	+ 21·2

* Re-exports exceeded imports by 206,385 galls.

UNITED STATES.—The preliminary returns of the production of petroleum in the U.S.A. during 1923, as published by the U.S. Geological Survey, show an increase of 30 per cent. over 1922, as given in the following statement. The most noteworthy increases by States are those of Arkansas 171 per cent., California 90 per cent., New York 25 per cent., and Wyoming 65 per cent. By fields, other than California, the Rocky Mountain field gives the highest increase, 59 per cent.

UNITED STATES OF AMERICA.

PRODUCTION OF CRUDE PETROLEUM, 1922 AND 1923.

Field and State.	Quantity in Barrels of 42 U.S.A. Galls. 1922.	1923.	Increase or decrease in 1923 compared with 1922.
APPALACHIAN—			Per cent.
New York	1,000,000	1,252,000	+ 25
Pennsylvania	7,425,000	7,253,000	— 2
West Virginia	7,021,000	6,402,000	— 9
Central and Eastern Ohio	4,751,000	4,916,000	+ 4
Kentucky	8,973,200	8,075,300	— 10
Tennessee	9,800	7,700	— 22
	29,180,000	27,906,000	— 5
LIMA-INDIANA—			
North-West Ohio	2,030,000	2,160,000	+ 6
North-East Indiana	239,000	253,000	+ 6
	2,269,000	2,413,000	+ 6

Illinois and South-West Indiana—			
Illinois	9,383,000	8,710,000 ..	— 7
South-West Indiana ..	848,000	792,000 ..	— 7
	10,231,000	9,502,000 ..	— 7
Mid-Continent—			
Oklahoma	149,571,000	159,873,000 ..	+ 7
Kansas	31,766,000	27,966,000 ..	— 12
Central and North Texas	83,314,000	99,104,000 ..	+ 19
North Louisiana	33,629,000	22,526,000 ..	— 33
Arkansas	12,712,000	34,459,000 ..	+171
	310,992,000	343,928,000 ..	+ 10
Gulf Coast—			
Texas	35,370,000	29,311,000 ..	— 17
Louisiana	1,747,000	2,250,000 ..	+ 29
	37,117,000	31,561,000 ..	— 15
Rocky Mountain—			
Colorado	97,000	67,000 ..	— 30
Wyoming	26,715,000	44,047,000 ..	+ 65
Montana	2,449,000	2,549,000 ..	+ 4
	29,261,000	46,663,000 ..	+ 59
California	138,468,000	263,729,000 ..	+ 90
Other	13,000	— ..	—
Total	557,531,000	725,702,000 ..	+ 30

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The Seventy-Fourth General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts on Tuesday evening, December 11th, 1923, the chair being taken by the President, Mr. H. Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A.

The President said that Mr. McCollum had kindly offered to read a paper on the Modern Rotary Drilling System, and this he had no doubt would prove very interesting, and lead to a good discussion.

The Secretary read the names of newly elected members, as follows :—

Members.—John Jackson Calderwood, Robert Mason Fletcher, William Gray, Victor Henny, Ernest Sheppard Pinfold, James McConnell Sanders.

Transference from Associate Member.—Herbert Theodore Mayo.

Associate Members.—Harry Standish Ball, William Edward Evans.

Transference from Student.—Brian MacSheehy Shelton Agar, David James Hamilton, Wilfred Henry Thomas.

Students.—Kilian Edgar Bensusan, Walter Cattrall, George Roxburgh Clark, Boris Daskevitch, Kenneth Dulake, Geoffrey David Jardine, John Berridge Kay, John Leslie Macleod, Herbert James Mason, Adolf Rauch, Stephen Stock.

Associates.—Sydney John Fortescue, Henry Sydney Fuller, Edward Lionel Johnson.

The following paper was then read :—

The Modern Rotary Drilling System.

By L. R. McCollum (Non-Member).

Since Col. Drake, of first oil well fame, brought in the discovery well at Titusville, Pennsylvania, in 1859, and John D. Rockefeller (then adult, though young) began handling lamp oil in 5-gallon tins over the counter of his general store at Cleveland, Ohio, the percussion,

or cable tool method of drilling which Col. Drake used, has changed but little in principle. The interval which has seen the rise and development of perhaps the world's most important industry, has been so short that the original Drake well is still producing.

The cable tool system proved to be a reliable method for drilling in most fields, and its use has been widespread throughout the United States, and in many foreign fields. With minor improvements added to the original design from time to time, it was used in the rapid developments following the first wells, and it spread throughout Pennsylvania, West Virginia and adjacent fields, gradually making its way over the country until it reached the Pacific Coast.

When in California, especially, more difficult drilling conditions were encountered, heavy crown-blocks, bull-wheels of steel and calf-wheels to facilitate the handling of casing, were added to the original equipment.

Later, exploitation work in the Gulf Coast regions of Texas and Louisiana encountered unconsolidated, soft and caving formations, which gave the cable tools a bad time. To combat these conditions the Rotary system was invented or rather developed upon the Fauck system, which had been in use in Europe since 1845.

By this method a rigid stem of pipe rotates a fish tail—or other type of bit—at the bottom of the hole, being assisted by the action of clay mud in the fluid state, pumped under hydraulic pressure, through the drill-pipe. The circulating mud also removes the cuttings from the hole.

This improved method, the Rotary system, had its inception in the Spindletop field of Texas, and in the course of some eighteen or twenty years has drilled approximately 25,000 wells.

So great were its virtues of speed and economy that modifications and improvements were soon added which enabled it to penetrate thick strata of extremely hard rock at great depths. This capacity has now been proved beyond the questioning of intelligent operators.

The extreme speed attained with this type of equipment, and the few strings of casing necessary, are its chief assets. It is not unusual in a rotary field for a good crew to average 450 feet of hole per day. Wells have been drilled to a depth of 5000 feet with only two strings of casing. The rotating action of the bit and drill-stem causes the mud to be thrown against the walls of the hole, plastering them thoroughly and penetrating porous formations to a very small extent, where it " muds-off " water and gas. This mudding of the walls saves casing, and prevents water and gas troubles, as the static pressure of the mud in the hole tends to balance excessive gas and water pressures.

One of the objections which is continually being raised against the rotary system by operators unfamiliar with its working, is

that there is the danger of mudding-off unknown oil-sands. There may be this danger in " wildcat " or unproved territory, especially in the hands of an unskilled or inexperienced workman, and to obviate it there has been evolved what is known as the Combination Rig. In this system, the derrick and machinery are provided for both types of drilling, and if conditions are met which, for any reason, cause the findings of the Rotary to be questionable, then the cable tools may be brought into play. The combination system is employed to a large extent in known fields where the rotary is generally used to drill through the upper formations at great speed, effecting a tremendous saving in time, trouble and expense, and the cable tools are used finally to drill into the oil-sand.

Government regulations in Rumania, Poland and some other countries still insist that the oil strata be penetrated with dry percussion tools only, because of the fear that oil levels may be flooded by the rotary mud-fluid. It has, however, been so conclusively demonstrated that the danger is a theoretical rather than a practical one, that many Government Mines Bureaus are revising this regulation, and in California it has been abolished altogether.

We can now say absolutely that if any well can be drilled at all, the combination rig will do it. If accurate logs of wells in a new locality are kept, and if, as is very desirable, Core Barrels are run and cores taken with the rotary equipment, it is easily possible to calculate the underground formations of the field, and if desired, do away with the cable tool feature of the combination, using straight rotary only.

Throughout this paper particular reference is made to the State of California. It cannot be avoided in any discussion upon the rotary system of drilling, as California is admittedly the home of all modern rotary development, practically all recent improvements in the construction of the machinery, and in the use of the rotary system, having emanated from this State. Rotary drilling practice in California has reached a higher level than anywhere else in the world, and the present huge production of oil in that State has only been made possible by the extensive use of the rotary.

The daily production of oil in California in March, 1922, was only 310,000 barrels, but it had increased to 870,000 barrels by August, 1923, due entirely to the rapid development made possible by the use of the rotary system.

There is, of course, no reason why the results being accomplished in California cannot be duplicated in other countries, and it cannot be disputed that in foreign fields, where the American drilling methods have been used in competition with other systems, they have, when *competently handled*, always proved the most satisfactory. They have more than met competition everywhere, and each day

finds them more generally proclaimed superior to any other system devised. For this reason foreign systems have never been able to secure any introduction into the United States.

Adaptability of the Rotary System.

In the Gulf Coast fields a light type of equipment is generally used, in view of the comparatively shallow depths drilled and the easy formations to be penetrated. The weight of the rotary machine used under these conditions is about 4600 lbs., but in California, where the heaviest equipment is necessary, the weight of the machine is over 8000 lbs. The standard size of rotary has a table opening of 20 ins. in diameter, but the heavy machine used where it is desired to commence and finish a well with large diameter casings, is provided with a 27½ in.-diameter table opening. This heavy machine was originally developed especially for Rumania and Russia, where oil is principally raised by bailing, but it has become so popular in California that it is now almost exclusively used there.

The heavy machine naturally involves a greater initial outlay, as all the equipment is of correspondingly solid construction, but it is ultimately more economical than the lighter type. In California, where the rotary has drilled as deep as 7200 feet, the heaviest and best constructed machinery is necessary.

It has only been during the past ten to twelve years that trained engineers have given serious consideration to the oil industry as a field for their endeavours. The present development of the rotary has been attained by the close co-operation between oilfield superintendents and drillers and the manufacturers. The manufacturers, knowing the abuse to which drilling machinery is necessarily subjected, have through their engineering departments developed the basic metals, heat treatments and manufacturing processes, which have finally developed the heavy, durable class of machinery at present marketed, but the ideas, the improvements and the developments have largely emanated from the man on the field—the actual practical operator.

Fig. 1 shows a combination rig used in California, which drilled to a depth of 6680 ft., and Fig. 2 is a view of the derrick floor of the deepest rotary-drilled well in the world. This well, which is situated in California, is at present over 7200 ft. deep, and no fishing trouble has been experienced.

Principle.

In the Rotary System the Drilling Tools consist of a flat bit in the form of a fishtail, mounted on the bottom of a string of drill-

pipe extending to the surface, where it is grasped and rotated by the table of the rotary machine mounted on the derrick floor. The whole string of drill-pipe is suspended from the tackle fitted with a swivel attachment so that the bit may be raised and lowered and its pressure on the bottom regulated. See Fig. 3.

While drilling is proceeding mud-laden fluid is pumped through a flexible hose to the connection of the swivel, down through the hollow drill-stem and out through holes in the bit. Here it mixes with the cuttings and carries them up between the drill-pipe and the walls of the hole to the surface. The mud-laden fluid plays a very important part in rotary drilling, and it is important that it should contain only very finely divided clay. It usually has the consistency of thick cream and a specific gravity of 1.4. The hydrostatic pressure of the column of mud enables high pressure gas strata to be penetrated with no danger of a blow-out.

On its upward passage outside the drill-pipe a proportion of the mud adheres to the walls of the hole, and plasters them to such an extent that any tendency to caving is overcome.

The Rig.

The rotary rig includes the derrick, or tower, and foundations for rotary machinery. It is built by a crew of rig builders in the average time of 35 man days.

The Derrick.

The derrick supports the crown-block, which carries pulleys or sheaves over which the hoisting lines pass. The rotary derricks vary in height from 112 to 130 feet, and are 24 feet square at the base: 120 feet by 24 feet is the ordinary size. These derricks are made extremely high in order that the drill-pipe may be withdrawn, dissembled, and set back in the derrick in "stands" of four joints each (each joint of pipe being about 24 feet long). This greatly reduces the work of taking out and replacing the drill-pipe when changing bits. The platform (called the "fourble board") from which the derrick man operates the elevators, is placed inside the derrick about 80 feet above the derrick floor. The derrick is braced and guyed with three wires on each leg to withstand wind pressures.

Rigging Up.

After the rig has been completed by the rig builders, the regular drilling crew moves in and builds the mud ditches and instals the rotary machinery. This takes from four days to a week.

Mud Storage and Ditches.

A wood-lined pit about 10 feet square by 10 feet deep is constructed just outside the derrick floor on the pump side. This serves for mixing and storing the mud, and as a suction box for the pumps. About 100 feet of wooden ditch conducts the mud from the top of the casing back to the mud pit. Here occurs the precipitation of the cuttings from the mud. The cuttings are shovelled out of the bottom of the ditch and disposed of, and the mud returns to the pit to be used again. Often very elaborate settling boxes are arranged in this ditch system.

Power.

Power is supplied by steam, gas or electricity. When steam is the method employed it is usually supplied by one large, portable locomotive-type fire-tube boiler. In very deep fields two or three boilers totalling about 140 h.p. are commonly used. The engine may be either a single-cylinder, double-acting, steam engine of 12 in. bore and stroke, or a 10 in. by 10 in. twin-cylinder double-acting steam engine. The twin-cylinder engine has several decided advantages over the single in rotary drilling, the chief of which is the alternating action of the pistons.

In rotary drilling it is continually necessary to reverse the engine rapidly when the bit encounters a break in the formation, or a boulder which it cannot penetrate nor dislodge. Unless the twisting force on the drill-pipe is quickly relieved, the pipe will be broken in two. It takes some appreciable time for the impetus of the heavy fly-wheel on a single-cylinder engine to be overcome and the engine reversed, but the reverse can be accomplished immediately with the twin engine. The flow of power from the twin engine is also much more regular and sustained, and there is ample power for rapidly raising a heavy string of drill-pipe from great depths. Both the single and twin-cylinder engines, whichever form is used, are provided with a chain sprocket for driving the line-shaft on the draw works.

In many fields where electric current is available, rotary rigs as well as cable tool outfits are being operated by electric motors. The standard equipment for running a rotary rig by electricity is a 75 h.p. induction-type motor, of 50 or 60 cycles. The equipment for this motor consists of a main and auxiliary controller with main and auxiliary resisters, oil circuit breaker and current transformer. The motor operates on alternating current, and the control equipment provides for a very wide speed variation, a range of 153 speeds being possible. The drive from the motor to the line-shaft is through a reduction gear, and from the gear to the line-shaft by sprocket chain. See Fig. 4.

The slush pumps are also operated by electric motor, the motor in this case being a 50 h.p. 60 or 50 cycle induction-type motor, and the control equipment practically the same as for the drilling motor. The slush pumps are of a slightly different design when electricity is the motive power, the steam end being replaced by gears with a heavy belt pulley mounted on the crank shaft. Two slush pumps are always used in a rotary rig, so that in the event of repairs being necessary on one, there is always another in reserve.

The power-driven pumps are provided in pairs with the pulleys mounted right and left hand, the motor being mounted on an adjustable base which permits lateral movement of the motor to transfer the driving belt from one pump to the other.

For gas and oil engines which are also used in rotary drilling the usual installation is a heavy oil country type 75 h.p. engine, which will run on either natural gas or a low grade distillate. Although internal-combustion engines are widely used for pumping wells, and are in fairly common use for cable tool drilling, their application to a rotary rig is of quite recent introduction and of limited extent, so that it is not possible at present to give an opinion as to the relative merits of oil and gas engines in comparison with steam or electrically driven rigs. When an internal-combustion engine is used the drive is stepped up from the engine to the line shaft *via* a countershaft. Whatever form of power is employed, all the controls are on the right-hand side of the draw works, which is the position in which the driller stands while operations are proceeding, and from which point he has full control of the draw works and the power unit.

The Draw Works.

This part of the machinery serves as a hoisting gear for handling the drill-pipe and as a transmission between the engine and the rotary machine. It consists essentially of three heavy, vertical timber posts, framed into the side of the derrick.

It carries a heavy line-shaft in bearings on the back near the top, and a heavy drum-shaft and drum in bearings on the front. The engine drives by a sprocket chain to a sprocket on this line shaft. The drum shaft is driven from the line shaft by the chain drives, one of a ratio of 11 to 27, and the other 12 to 18. Either of these drives may be engaged by a clutch operated from the driller's station at the right hand post of the draw works. The low-speed clutch is designed with bevel jaws, so that when the high-speed clutch is thrown in it will overrun and be automatically disengaged. The two flanges on the ends of the hoisting drum are provided with brake drums encircled by powerful, asbestos-lined brakes, operated by the brake-lever at the driller's station. The ends of the line-shaft project beyond the bearings and are fitted with heavy iron "cat-

heads" used like a capstan for light hoisting and pulling in connection with a single 1½ in. Manilla cable passing over an extra pulley on the crown-block. Fig. 5 shows a plan of a chain-driven rotary machine.

The tendency is for the rotary machine to be run at continually increasing speeds. There is now available a three-speed rotary draw works, which renders it possible for drilling to proceed at a greater rate. The clutches on the draw works are now operated by foot pedals instead of the lever which the driller formerly had to operate sideways with his knee.

The Rotary Machine.

The rotary machine is a device for gripping and turning the drill-pipe. It consists of a heavy, horizontal, steel turn-table carried by a heavy, annular, cone-roller bearing on a massive base. The table is held down on the bearings by large hold-down brackets bolted to the base and engaging a flange on the vertical skirt of the table. The drill string, the upper or working joint of which is square, passes through a square hole in the table, and is driven by suitable bushings engaging both table and drill stem. The table has gear teeth on its under side, which are engaged by the pinion on the pinion shaft carried in bearings on the base. The pinion shaft is driven, either by a sprocket chain from the line-shaft of the draw works, or by a direct shaft drive. (See Fig. 5).

The Shaft Drive.

The chain-drive rotary is more widely used, but another form of drive, known as the shaft-drive, has been developed. In this case the driving chain from the line-shaft is taken to a shaft-drive attachment mounted on the derrick foundation behind the draw works. This attachment operates by means of bevel-pinions, a shaft which is connected with the pinion shaft of the rotary machine. This arrangement gives a more direct drive, and has the great advantage of leaving an unobstructed derrick floor with clear space all round the rotary machine. See Figs. 6, 7, and 8.

When the rotary machine was first introduced, a clutch was provided on the pinion shaft for disengaging the drive from the rotary table. A clutch was also later installed on the line-shaft of the draw works, to serve the same purpose, but the construction of the rotary machine has now been simplified, and strengthened by the elimination of the pinion shaft clutch, the one on the draw works being quite sufficient for all purposes.

A recent introduction is the embodiment of mechanism in the rotary table for screwing up and unscrewing drill-pipe and casing. For this type of rotary it is claimed that much time is saved in

FIG. 1.

COMBINATION RIG.

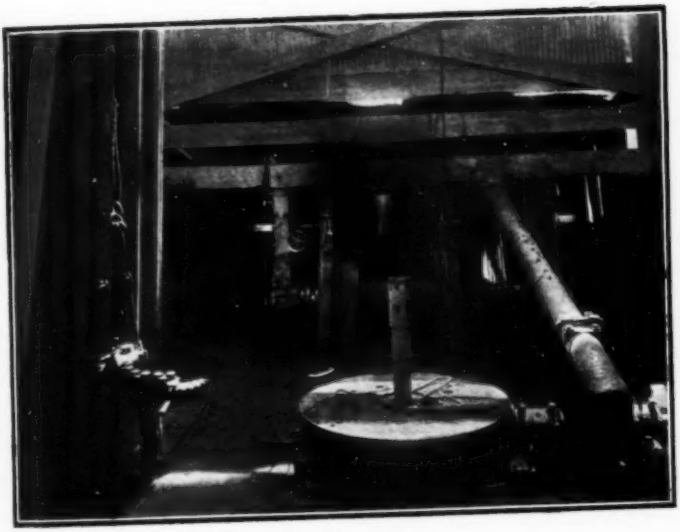


FIG. 2.

THE DEEPEST ROTARY-DRILLED WELL IN THE WORLD, CALIFORNIA, AT PRESENT OVER 7,200 FEET DEEP.

FIG. 3.

INTERIOR VIEW OF MODERN ROTARY RIG, SHOWING MACHINERY AND EQUIPMENT.

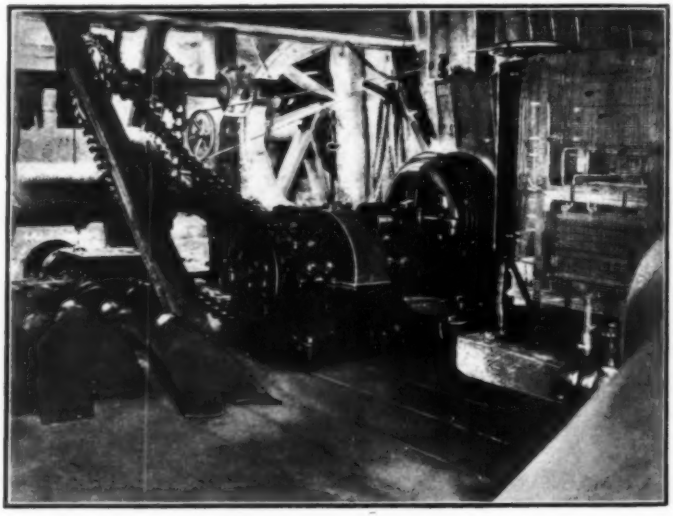


FIG. 4.

VIEW OF THE ELECTRICAL INSTALLATION OF A COMBINATION ELECTRICALLY-DRIVEN RIG.

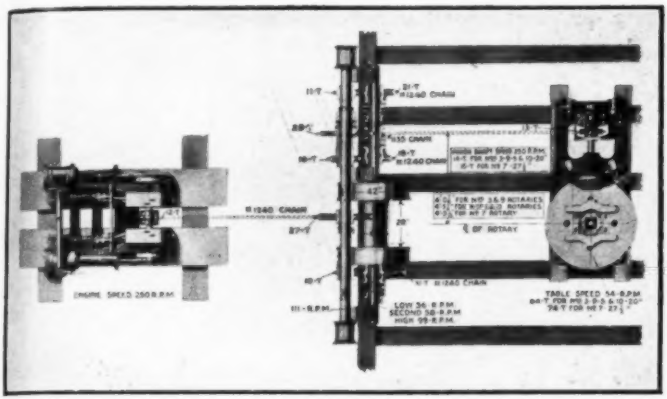


FIG. 5.

PLAN OF MODERN CHAIN-DRIVEN ROTARY MACHINE SHOWING CONNECTIONS TO DRAW-WORKS AND TWIN-CYLINDER ENGINE, WITH RESPECTIVE SPROCKET SPEEDS.

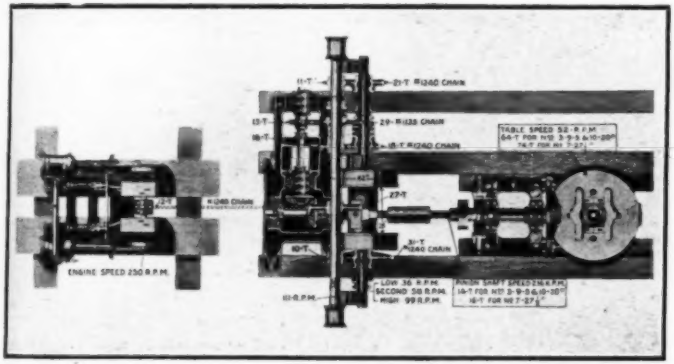


FIG. 6.

PLAN OF MODERN SHAFT-DRIVEN ROTARY MACHINE SHOWING CONNECTIONS TO SHAFT-DRIVE, DRAW WORKS AND ENGINE, WITH RESPECTIVE SPEEDS INDICATED.

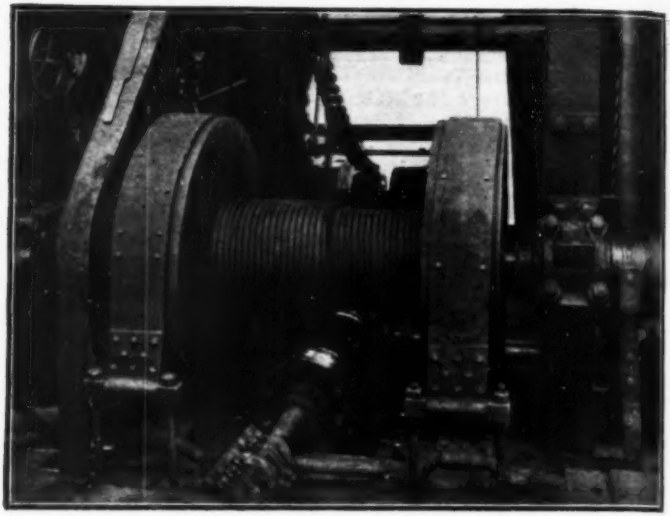


FIG. 7.

THE ASSEMBLY OF A SHAFT-DRIVE ATTACHMENT FOR A ROTARY RIG, SHOWING UNIVERSAL AND JACK SHAFT COUPLINGS.

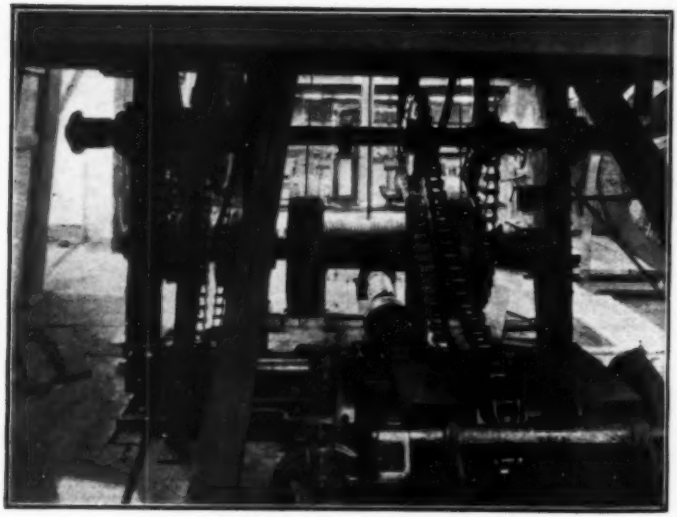


FIG. 8.

ASSEMBLY OF A SHAFT-DRIVEN ROTARY, SHOWING SPROCKET-DRIVE FROM ENGINE TO LINE SHAFT AND FROM LINE SHAFT TO SHAFT-DRIVE ATTACHMENT.

performing these operations in the hands of experienced and careful drillers. There is one observation, however, which practical experience has developed. Where the screwing and unscrewing device is used with speed greater than that employed by the tube mills, in making up pipe or screwing on couplings, the lubricant on the joints is often destroyed, which creates carbonisation or burning of the threads. Where competent labour is employed, this danger is, of course, avoided. The design has the disadvantage of requiring a considerable amount of complicated mechanism in the rotary table which is liable to serious wear and damage ; also, of course, the initial cost of the machine is much higher.

Another development which is now being experimented with is the regulation of the feed of the rotary bit on a steam or electrically-driven rig. By means of regulators, when a torsional strain is placed on the bit nearly sufficient to cause a twist-off, the entire string of drill-pipe is automatically raised to relieve the pressure. This device is at present in a purely experimental stage, but if improvement along such lines is successfully continued, it may not be long before we shall be able to dispense even with the driller.

In order to ascertain the weight on the bit, and to regulate this weight according to requirements, various types of stress indicators have also been developed. The most reliable at present in use is placed in the dead line between the crown block and casing block, and it therefore actually registers the strain in the line, minus a slight friction of the ropes in running over the sheaves. It is a simple matter from the strain indicated and the number of lines used to calculate the dead weight in the well.

Another device to serve the same purpose is used on several of the Shell Company's wells in California. In this case advantage is taken of the compression of the derrick legs to indicate the weight hanging in the well. The driller determines what length of pipe he will allow to rest on the bit and proceeds to set a zero mark on the indicator for this weight. Any more or less weight on the ropes will throw the recording needle to either side of zero. Though this idea may appear crude it has been developed to the point where it gives satisfactory service, and can be used by any driller without special training.

Pumps.

The mud-laden fluid is circulated by two powerful, direct-acting, duplex steam pumps, working alternately. The abrasive action of the mud causes the packing on plungers and valves to be comparatively short-lived, and these are designed for easy replacement. The two pumps permit of continuous circulation (if necessary), one pump operating and the other kept in reserve. For light drilling these pumps have 5¾ in. water cylinders, 10 in. steam cylin-

ders, and 12 in. stroke. The heavy duty pumps are 6¾ in. by 12 in. by 12 in. or 6¾ in. by 12 in. by 14 in. Each pump has a separate suction pipe to the mud pit. The discharges are connected by a manifold to a stand pipe running for about 20 feet up the side of the derrick. A flexible hose connects the top of this pipe with the swivel on the drill stem.

The Hoisting Tackle.

Heavy hoisting equipment is necessary for handling the drill pipe and casing. Such equipment consists of the casing pulleys on the crown-block, the travelling pulley block (Fig. 9), and the casing line which is roved through these pulleys. For starting the well a four-line tackle is used, and the number of the lines is increased as the hole is deepened until as many as nine lines are used. The casing line is usually a ⅞ in. or 1 in. wire line of 6 by 19 construction. The free end of the line is spooled on the hoisting drum at the draw works.

Efficient lubrication of the crown block and casing block is most essential, in order to save wear on these parts, and to increase the safety of operation.

Crown blocks for deep drilling are now made entirely of heavy steel beams, 40 or 50 lb. per ft. weight. The pulleys are mounted in oil-retaining bearing boxes, which can be so adjusted that the pulleys can be arranged at any point along the beams. The type of travelling block which is now generally used is known as the overbalanced type, in which the sheave pin is considerably above the centre of the block. This gives sufficient weight below the pulleys to prevent the block tilting over and becoming entangled in the wire lines, when it is being rapidly raised or lowered, free of weight. A heavy casing hook is attached to the becket in the body of the travelling block.

For rotary drilling it is advisable to use the type of hook provided with a spring on the neck. This spring is powerful enough to support one stand (4 joints) of drill-pipe, and facilitate screwing up and unscrewing the tapered tool joints between stands without damage to the threads, and with great speed. (Fig. 9.)

The Swivel.

This device serves as a swivelling connection between the hook and the rotating drill-pipe, and facilitates the introduction of the mud-laden fluid under high pressure. The swivel must rotate freely when supporting the combined weight of drill-stem, drill-pipe and bit, and is subject to many shocks. The modern swivel is the most refined piece of machinery on the rotary rig. It is automatically lubricated by the oil bath and gives absolutely no trouble. (Fig. 9.)

The Drill-Stem Attachment.

This device is the means of transmitting the rotary motion of the table to the drill-pipe. It takes the place of the old grip-ring device, which was clamped directly on to the round drill-pipe. The drill-stem was introduced when the square stem was first brought into use.

The stems now used are of either square or grooved section, and are drilled with a hole longitudinally through the middle to permit the passage of mud fluid. It is grasped by bushings which fit in the rotary table and engage the drill-stem. In the drill-stem attachment are also slips for holding the drill-pipe in the table when it is being inserted or withdrawn. The rotary table can also be used as a spider for holding various sizes of casing slips, bushings being provided so that all casing used in the well can be inserted without the use of a special spider and slips, and without moving the rotary machine from its position on the derrick floor. (Fig. 9.)

Drill-Pipe.

The drill-pipe generally used is either 6 in. or 4 in. size, though when the diameter of the well decreases below 6 in. casing, it is necessary to use smaller drill-pipe still.

The first drill-pipe used was ordinary line pipe, but this soon showed itself to be unsatisfactory. Heavier pipe was then made which was stronger than the early rotary machines, so that in the event of failures, it was the machine itself which became damaged.

The rotary machines were then made stronger and heavier. Lapwelded steel drill-pipe was introduced, which proved fairly satisfactory until the present heavy steel rotary became common. The specification of pipe which is now used is generally seamless steel, the ends of each length being internally upset to a double thickness for some distance beyond the end of the threaded portion. It is just at the back of the coupling that twist-offs are most likely to occur, and it is at this point that greater strength and wall thickness is provided by the process of upsetting. Lapwelded drill-pipe is unsatisfactory, principally on account of its low tensile strength, which is only between 45,000 and 55,000 lbs. per square inch, it being impossible to use higher carbon material on account of the necessity for welding. Also, in the event of a twist-off with lapwelded pipe, the break usually runs for some distance along the seam, and this makes it very difficult to run a fishing tool over the lost pipe.

Seamless steel material, on the other hand, has a tensile strength of about 70,000 lbs. per square inch, and is much less liable to twist-offs. When a twist-off does occur, however, the break is generally clean, so that there is very little difficulty in fishing. The weld in lapwelded pipe is naturally a source of weakness, and

it is calculated that at this point the strength is only 92 per cent. of that of the walls of the pipe.

As previously mentioned, the drill-pipe is generally made up in stands of 4 lengths each, so that a tapered tool joint is required at every 4 lengths, or approximately 96 feet. These conical screwed

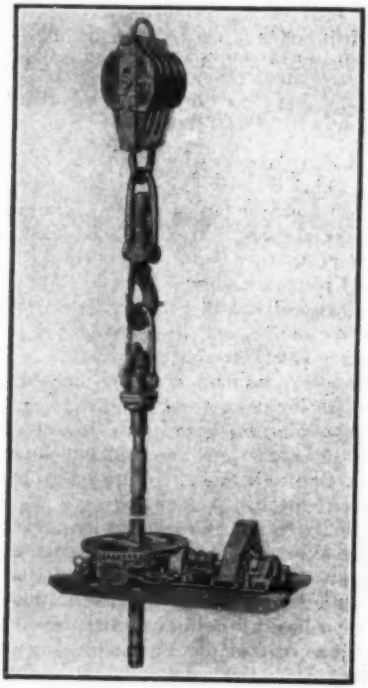


FIG. 9.

MODERN ROTARY ASSEMBLY, SHOWING ROTARY TABLE, DRILL STEM, SWIVEL, SPRING CASING HOOK AND TRAVELLING BLOCK, WITH PATENT LATCH ON THE HOOK AND WIRE LINE GUARD ON THE BLOCK.

joints with coarse threads facilitate the assembling of the drill-pipe. It is common practice now for the collars on the drill-pipe when it is made up in stands to be " spot welded " to the pipe, so that the joint is practically solid. The drill pipe immediately above the bit is subjected to transverse stresses in addition to torsional stresses, and a thick walled joint of pipe called a drill collar is used here. The drill collar is provided with a shoulder which affords a

hold for the elevators when making up the string, or for the overshot dogs in fishing.

The tendency in deep drilling is to increase the weight on the bit by using a considerable length of these heavy drill collars, as much as 80 feet being screwed together in some fields. When drill collars are screwed up in this manner, they are each provided with a box and pin joint, instead of the usual box at each end, as is the case when only one drill collar is used. For drilling in large diameter holes the drill collars are also made 10 inches outside diameter.

Drilling Bits.

For ordinary drilling in everything but very hard rock, the fish-tail bit is used. This is a simple steel bit and can be easily re-dressed when worn down or out of gauge. The diamond point bit is used only in special cases, for example in drilling past lost tools or side-tracking pipe or other objects lost in the hole. The 4-way bit is sometimes used to ream the hole prior to the insertion of casing, but it has certain disadvantages, and the use of a rotary under-reamer is far preferable.

Rotary drilling bits of these types should be manufactured of electric steel, because it can be tempered in water at the location without any subsequent failure in the steel. Ordinary steel should actually be tempered in oil, but this is not always possible on a drilling rig, with the result that tempering is done in water, and the bits made of straight carbon steel thus tempered very rarely produce the desired results.

The rotary system can penetrate even the hardest of rocks by the use of special bits. There are various types of these, the best known of which are the cone rock bit and the disc bit. The cone bit is provided with two circular grooved and milled cones mounted at the bottom of a heavy bit body, which revolve and crush the rock as the drill-pipe is rotated. The hole is kept to gauge by side reamers mounted above the cones, and an elaborate lubrication system for the whole bit is provided to insure perfect operation of all parts. These bits have proved very successful in some of the hardest formations. Care must be exercised as to the amount of weight imposed upon them.

The disc bit consists of a heavy body with two sharp-edged discs mounted at the bottom slightly eccentric. When this bit is rotated the discs exercise a slicing action which rapidly makes hole through tough formations, too hard for the ordinary fish-tail bit, and not sufficiently brittle to be crushed by the cone bit.

Another form of rotary bit which is used in easy and soft formations is the collapsible bit, in which two blades mounted on a series of toggles are lowered on a wire line through the drill-pipe

and emerge at the bottom. The advantage claimed for this type of bit is that it is not necessary to withdraw the whole string of drill pipe in order to change a bit.

Commencing the Well.

Before the actual drilling is started, a hole about 3 or 4 feet square is dug by hand below the derrick floor to a depth of 8 or 10 feet and lined with a wooden box. This is called the conductor box and serves to collect the rotary mud and conduct it to the mud ditch. A crew of 15 men is divided into 3 shifts of 5 men each; these 5 men include a driller, derrick man, fireman and 2 helpers. As the bit penetrates the formation it is lowered by releasing the brakes on the hoisting drum of the draw works, permitting the drill-stem to slide down through the driving bushings. As the hole is deepened drill-pipe is added between the square drill-stem and the string in the hole. In soft formations the bit may run for six or eight hours without becoming dull, while in hard sandy formations it may require re-dressing after only a half-hour's drilling. It is then necessary to withdraw all the drill-pipe and attach a new bit.

This drill-pipe is handled by means of hoisting tackle, elevators and drill-pipe slips. It is unscrewed at each of the tapered tool joints, and stands of pipe are placed upright in one corner of the derrick. The tool joints are unscrewed with heavy tongs which grip the cylindrical surface, and are operated by force applied from the steam engine over the "catheads" on the line-shaft by means of a rope to the handle of the tong.

Elevators for handling drill-pipe should be provided with links not less than 5 feet long. This renders it easy for the derrick man to reach the top of the stand of drill-pipe and guide it into its place at the side of the derrick. A recently marketed form of drill-pipe elevator is provided with latches mounted on springs, which open when lowered on to the rotary table, permitting the links to be swung clear of the elevator body. The elevator at the same time acts as a support for the drill-pipe, without the use of slips, the whole weight resting on the elevator at the tool joint.

The Use and Action of Mud Fluid in Rotary Drilling.

A subject which has been very extensively discussed, and on which opinions vary considerably, is the action of the mud-laden fluid in a well being drilled by rotary.

Horizons of high gas pressure are successfully penetrated by the rotary with no special precautions. From the time the well is

started until the casing is set, the hole is kept full of mud-laden fluid, and the hydrostatic pressure of this fluid will overcome all excepting very excessive gas pressures. In proven fields, where the depth of the oil horizon is known, wells are extensively brought into production with the rotary. When the oil-sand is penetrated the oil-string of casing and the tubing are inserted, clear water is pumped down between the casing and the tubing, forcing the mud-laden fluid out through the tubing. This washes the mud from the sides of the oil-bearing formation, and decreases the hydrostatic pressure, permitting the well to flow.

Where rotary wells are drilled in a non-flowing territory, the circulating fluid is thinned by constantly adding water until the washing process has cleaned the strata ; after which the fluid is entirely bailed out and the well is brought in and pumping equipment is installed.

With the object of securing definite information on the action of mud-laden fluid in a rotary drilled well, various experiments have been carried out, not only with laboratory apparatus, but on the field, the objects being to ascertain the relative penetrative effect of clear water, and of mud fluid in different kinds of formations.

The laboratory experiments have included the forcing of water and mud fluids of different specific gravities through a column of sand under known pressures. The result of these laboratory experiments proved that the clay mud quickly adhered to the sides of a channel cut through a column of sand, and this mud wall remained permanent whether circulation of the fluid was continued or not.

When water was slowly circulated through this channel a certain amount of the plastered clay was washed away, but a stable condition was soon reached, after which there was no more erosion, and water circulating indefinitely remained clear.

After the water circulation was stopped, however, the walls commenced to cave almost immediately, and the entire wall soon disappeared.

More definite experiments were carried out by the Union Oil Co., of California, in conjunction with the State Oil and Gas Commission. A sample of rock weighing approximately a ton was used for the experiment, this rock being taken from a formation which has been exposed to the elements for centuries and was free from saturation, either of water or of oil. A 1¼ in. hole, 26 in. deep, was drilled in it, a nipple leaded in the top and preparation was made to raise a pressure of at least 4000 lbs. Water was first put in the hole, and an attempt made to produce pressure, but the formation absorbed the water rapidly. Mud fluid from the rotary sump hole was then substituted, and pressure immediately began to build up. Pump pressure was kept at 200 lbs., all one night,

and the next day was gradually increased to 400 lbs., at which point the rock opened at the seams, which originally were only just discernible.

As no further mud could be forced in, the rock was broken up into numerous sections. In no one of the dozen parts observed was there any indication of the mud having penetrated even a fractional part of an inch, although when freshly broken the travel of the clean water first put in could be plainly observed.

Later, another sample of the same formation, weighing 50 lbs., was taken and divided equally in half. One of these pieces was submerged in water for two hours, and upon its removal was found to have absorbed 3 lbs. weight of water, and after a further submergence of 24 hours had absorbed only a few ounces more.

The other block of rock was placed for 24 hours in a tank of 24 gravity oil straight from the well. At the end of 24 hours it was weighed and found to have absorbed practically the same amount in weight of oil as the first sample had of water.

These experiments, with sand, porous rock and different formations, conclusively proved that whereas water and oil were rapidly taken up, the mud-laden circulating fluid only created a film or deposit on the inner wall or lining of the hole.

The nature and specific gravity of the mud fluid has a considerable effect on the speed of drilling. A uniform mud will make hole faster than mud which is thinned at intervals. Since mud thickens continually during the drilling operation, it will eventually get so thick that drilling is retarded, and it will become necessary for more water to be added to the sump. This operation should be so regulated that the mud will be always kept at a uniform consistency.

The velocity of the mud fluid also has a very considerable effect upon drilling speed. It has been demonstrated, when drilling in laminated shale for example, that an increase of velocity from 1¼ to 1½ ft. per second up the hole, carried out three times the quantity of cuttings. Velocities of mud in a well are comparatively low, as shown by the annexed table:—

Diam. hole. in.	Diam. drill-pipe in.	Velocity in feet per second. GPM. 100	GPM. 200	GPM. 300	GPM. 400	GPM. 500
7⅞	3	0·82	1·46	2·46	3·28	4·10
7⅞	4	0·88	1·76	2·64	3·52	4·40
9	4	0·62	1·24	1·86	2·48	3·10
9	5	0·84	1·64	2·52	3·36	4·20
11	4	0·38	0·74	1·14	1·52	1·90
11	5	0·45	0·90	1·35	1·80	2·25
11	6	0·53	1·06	1·59	2·12	2·65
15	6	0·23	0·46	0·69	0 92	1·15
19½	6	0·12	0·24	0·36	0·48	0·60

An experienced driller keeps the velocity as high as possible, without caving the hole, and this is where experience is necessary, although the slightest cave can be detected immediately and means taken to stop it.

The velocity in large holes cannot be as high as in those of small diameters, because of a loss of the arch effect in supporting the sides of the hole. In drilling large wells, consequently, the mud must be colloidal and heavy and the velocity relatively low. Cuttings come up slowly although the same velocity brings out the same quantity, but the mud is heavier, due to the large amount of cuttings carried in suspension.

The experiment above referred to, and others, show that the depth of penetration of a low gravity mud fluid into a porous formation is greater than that of a heavier gravity. In general practice mud of a specific gravity of 1·13 gives the best results.

Where the hole has been drilled with a mud fluid of this gravity it has been found that the mud wall of the hole is more permanent, and the sand carried in suspension settles out in the mud ditch faster than when mud fluid of heavier gravity is used. For a fishing job in a deep well the use of a lighter gravity mud fluid sometimes proves a great disadvantage, as the sand held in suspension may settle around the lost tools, freezing them before it is possible to run the fishing tools into the hole.

Use of Core Barrels in Rotary Drilling.

The formations encountered can be satisfactorily recorded by the expert driller. He can easily tell by the action of the machinery when he encounters a change in formation, and samples of this formation can be taken from the rotary mud flowing to the surface, making an allowance for the time needed by the mud to travel up the hole. Where very accurate samples are advisable, a core barrel is used. This is substituted for the bit, and brings up an intact section of the formation.

Opponents of the rotary system invariably cite, as an argument against it, a supposed inability of the system to accurately sample the formations passed through. This argument might have been used in the early days of the rotary, and against any other system in the early stages of its development.

However, recent developments in core barrels have made it possible to take exact samples of the formations drilled at any depth, and many wells in California are now being drilled, taking cores continuously. While this procedure increases the time required for drilling, the information secured regarding the underground formations is usually well worth the additional expense.

Up to the middle of 1921 core drilling was only in the experimental

stage, but by the autumn of the same year it had become an established practice.

Mr. Joseph Jensen, Chief Geologist for the Associated and Amalgamated Oil Companies, shows in a paper recently read before the American Association of Petroleum Technologists at Los Angeles, that when Companies take their own cores, it is necessary for drillers to have a certain amount of special training.

Core barrels are of both the single and double barrel type, and on most of the single barrel types the circulating mud fluid is from 3 to 20 feet from the cutting edge of the barrel.

If too much weight is put upon the core barrel during rotation, high temperatures are soon generated by the friction. These temperatures were in many cases above the fusion point of the formation being cored, which resulted in obtaining cores that were badly fused. In every case the sample obtained from a fused core was so badly metamorphosed that it gave no information about the formations from which it was taken.

The double core barrel is constructed with the object of overcoming the difficulty of fusing cores. It is provided with means of cooling the barrel itself and of withdrawing the core easily.

There is an admixture of circulating mud with most core samples. Sometimes it occurs as a thin coating covering all of the sample, and in many cases the circulating mud fills cavities in the core, though it is not difficult to distinguish the rotary mud from the actual formation taken from the bottom.

After cores are taken (if they do not show unmistakable signs of containing petroleum), ether and chloroform are used in testing, when the presence of oil is indicated by discoloration of the sample. The usefulness of a core barrel can hardly be over-estimated, particularly in wild-cat wells and in newly discovered areas. It not only shows the presence or absence of oil, but gives definite knowledge about formations which are important for water shut-offs and for correlating different wells in a field.

It may be interesting to have the description of a double type core barrel developed by Mr. Kinnebrew, Superintendent of the American Oilfields Co.

It is constructed of 3-inch tubing for the inside barrel, and of 6-inch drill-pipe for the outside. The 3-inch tubing extends only 2 inches below the 6-inch drill-pipe. This assembly is about 5 feet long. Teeth are cut in both casings of the barrel. Between the 3-inch tubing and the bushing which screws into the drill-stem is 1 foot of perforated 3-inch tubing and a ball valve which permits the fluid in the 3-inch tubing to pass out.

This prevents the core from being washed by the circulating fluid or by the fluid in the well when pulling out. Cores up to 4 feet in length have been taken with this barrel, and for examina-

tion after withdrawal the 3-inch tubing containing the core is cut into 1-foot lengths, and each length is then split longitudinally.

Using Rotary Underreamers.

The problem of reaming a rotary hole is becoming more and more important, and though some operators use a four-way bit to enlarge the hole prior to inserting casing, its use is unsatisfactory. A rotary underreamer has now been devised on somewhat similar lines to the cable tool underreamer. The cutters, however, are mounted to withstand the rotary motion. This tool has been found to be very effective in operation, and the danger from twist-offs is very much less than in using the four-way bit or even the ordinary fishtail.

Casing the Hole.

One of the chief advantages of the rotary system is the great saving in casing. The following are comparisons of the casing used in rotary-drilled wells compared to the diameters used in cable tool drilling.

2400 ft. Well.

Rotary.	Cable Tools.
200 ft. 10-in. Casing	40 ft. 15½-in. Casing
2400 „ 8¼ „ „	200 „ 12½ „ „
5⅛″ Liner or 6½″	1000 „ 10 „ „
Casing Oil String.	2400 „ 8¼ „ „
	5⅛″ Liner or 6½″
	Casing Oil String

4400 ft. Well.

Surface Conductor.	Surface Conductor.
3750 ft. 10 in. Casing	200 ft. 18-in. Casing
4400 „ 8¼ „ „	750 „ 15½ „ „
5⅛″ Liner or 6½″	1450 „ 12½ „ „
Casing Oil String.	2500 „ 10 „ „
	3400 „ 8¼ „ „
	4000 „ 6½ „ „
	4400 „ 4½ „ „

Inserting Casing.

The casing programme in different fields has to be adapted to local conditions, but a typical instance may be cited in the Long Beach, California, field. The first few wells in this field were drilled to the cementing point with rotary and then finished with cable tools. With the exception of these early wells all the drilling has since been by the rotary method only.

The time taken to drill the wells entirely with rotary tools is

only about a quarter the time necessary to drill the well to the cementing point with rotary and then finish with cable tools.

With the rotary it has been possible to finish a well for production to a depth of 5500 feet in approximately 120 days. It is becoming common practice in this field to finish wells 1800 to 2500 feet below the last shut-off point. This necessitates setting an oil-string with 1000 to 2500 feet of friction.

In the Long Beach field the conductor casing is cemented at depths varying from 600 to 1000 feet. This string cases off the loose surface formations and also provides means of anchoring the water string. Water strings are cemented between 2300 and 4500 feet. It has been found advantageous to maintain the largest size hole possible, so that the well can be deepened if desired. On account of the great amount of friction on long strings, it is the general practice in the field, after setting one string, to omit the next succeeding size and set the next smaller size—*i.e.*, if 10-inch casing is used for the water string, 6¼-inch casing is used for the oil-string.

The oil-string is landed with screen pipe on the bottom, usually extending to the shoe of the water-string and open to the full thickness of the productive oil measures.

Another casing combination frequently employed is as follows:—

A 27-inch diameter hole is drilled for the 18-inch conductor casing, and after cementing this string a 17-inch hole is drilled to the cementing point, where the 11-inch casing is inserted for the water-string. The hole is then reduced to 10⅝ inches diameter, which size is carried to the cementing point of the 8¼-inch casing. After setting this string a 7⅝-inch hole is drilled to the completion depth, which is sufficiently large to set the 5½-inch liner. Six-inch drill-pipe is employed in drilling the hole to the cementing point of the water-string. After this has been set the 6-inch drill-pipe is broken down and replaced with 4-inch, which is used in the 11-inch and 10-inch casings.

To drill in through 8¼-inch and 6¼-inch casings 3-inch drill-pipe is customarily used, as it is easier to recover in the event of a fishing job.

These long strings of casing, some of which weigh over 100 tons, are now successfully landed and cemented with great rapidity. This is commonly done in California, using a special type of check valve and a particular pattern of shoe guide or floating plug. The check valve closes when the pressure on the outside is greater than that inside the casing. It is customary to place the check valve in the shoe guide, the casing shoe being threaded for both, and as each joint of casing is introduced it is filled with water until approximately 1000 feet has been set in the well. The pressure inside and out up to this point is equalised.

From there on no more water is added for a considerable depth, and this practically makes of the string of casing a float with the weight at the bottom. It is easily possible by proper manipulation to actually float this string to the desired position with very little, if any, strain on the casing line, brakes or draw-works. When the string is landed the casing is filled to the surface and the pump started. As soon as the pressure inside exceeds that outside the pump will force the mud fluid or cement through the shoe guide up outside the casing. After the casing is set the check valve and floating plug are drilled up. By this means many of the wells at Santa Fé Springs, California, have set as much as 3800 feet of 11-inch by 60 lb. casing of a total weight of approximately 230,000 lb. Other strings set in similar fashion include 5282 feet of 8¼-inch by 36 lb. casing and over 5500 feet of 6¼-inch by 26 lb. casing, weighing even more than the strings of larger pipe.

This method of floating in casing has the advantage of greatly reducing the impact if the casing parts and falls to the bottom.

Long strings of drill-pipe are also run in the wells by similar means, a check valve being inserted at some point above the drill collars.

Ten years ago, 95 per cent. of all drilling in California was done with cable tools, whereas at present over 95 per cent. is done with rotaries. In Texas and Arkansas 100 per cent. of the drilling is accomplished with rotaries, except in the Breckenridge district.

Shutting-Off Water.

The process of cementing is used almost exclusively for making a water tight joint at the bottom of the casing. Cement is pumped down through the casing which has been lifted off the bottom a few feet, and up around the casing outside. Sufficient water is pumped in on the top of the cement to force it all out of the casing, which is then lowered to the bottom.

Some modifications of this system use wooden plugs ahead of, and behind, the column in order that it will not mix with the mud and water.

When all the cement is out of the casing and the upper plug encounters the lower one at the bottom of the hole, the pumps stop owing to the back pressure, and valves at the casing head are closed. The well is then allowed to stand some days until the cement is set. In some cases where there are thick clay formations, the casing is pressed some considerable distance through the clay to effect a water shut-off if the source of the water is not very strong.

Fishing Jobs.

Fishing jobs with the rotary system are few and simple, nearly

all are caused by the drill-pipe twisting off. A simple device, known as an overshot, is run down on the recovered pipe. This is passed over the upper end of the lost pipe and springs attached to its inner surface catch under the first collar of the lost pipe, when it can be pulled to the surface.

Besides the overshot, the taper tap is sometimes used. This tool is run into the hole in the same manner as the overshot and enters either a water course in the tool joint or the inside of the drill-pipe. A slow, careful rotating motion is applied, and the tap cuts a thread, makes its own connection, and becomes a perfect joint. The lost portion is thus removed. The trip or wash down spear and the wall hook are employed as in cable drilling, except that they are attached to, and run on, the drill-pipe.

Speed in Rotary Drilling.

One of the most remarkable examples we have of the successful development of a field by the rotary system is the Tonkawa field in Oklahoma. The conditions here presented more difficulties than any other Oklahoma territory. The records of twelve wells completed by cable tools in the early development of the field show that it required an average of 147 days for each well. An average compiled from twelve wells drilled by rotary tools and completed by cable tools shows that similar wells were completed in fifty-one days, including cementing casing, standardising the rotary rig and drilling in with cable tools.

At Tonkawa drilling conditions are extremely hazardous for cable tools. Several shallow gas sands above 1000 feet made blow-outs frequent, and a number of gas wells completed at these depths produced as much as 50 million cubic feet daily. Such quantities of mud were required to hold these gas pressures back that progress with the cable tools was very slow. After passing through the gas sands, caving formations were encountered which made it necessary to carry the pipe close behind the tools. This made collapsed pipe, frozen pipe, with their consequent fishing and underreaming jobs, so frequent that cable tool contractors spent many weary months in penetrating the formations, and in the big majority of cases actually begged to be relieved of their contracts.

One typical instance of a cable tool well in this field may be mentioned :—

On December 13th, 1921, installation of the rig was completed. The hole was spudded in on January 4th, 1922. January 10th, 15½-inch casing was set at 686 feet. By January 19th the top of the gas sand was reached at 870 feet and 12½-inch casing was run. After eighteen days the gas had been mudded off, and the hole was being underreamed to set the 12½-inch casing to a total depth of 1017 feet.

On February 7th the contractor began drilling in 10-inch casing at 1025 feet. Then came a series of caves, boulders and frozen pipe jobs requiring so much delay that it was April 11th before the hole reached 1890 feet. Here 8¼-inch casing was introduced and drilling and underreaming proceeded for another month. At the end of that time similar obstacles resulted in the freezing of the 8¼-inch casing. The 6¼-inch casing, after a considerable period of drilling, underreaming and fighting the formations, was landed to a total depth of 2080 feet on May 12th.

On May 15th, at a depth of 2118 feet, 22,000,000 cubic feet of gas was encountered. Four days later this had been mudded off and drilling proceeded toward the 2600 foot sand.

On May 31st, with the hole drilled to a depth of 2137 feet, it was underreamed in order to carry the 6¼-inch casing to the bottom. With the casing set at this depth, drilling began again on June 9th, when the tools were lost.

Then followed a fishing job which continued two months and twenty-five days. The hole was finally plugged with the tools in it on September 5th, practically nine months after the work started.

In contrast with this well it is interesting to mention the log of a rotary well drilled on practically the same location.

Drilling began on September 5th, 1922, the day the cable tool hole was plugged as a failure. On October 17th, a little over forty days later, the well was drilling at 2000 feet. On November 7th, the 8¼-in. casing was set at 2432 feet, and the derrick was prepared for the reception of the cable tools.

On November 28th, the cable tools were drilling at 2505 feet in 6¼ in. casing. On December 3rd, 5 ⅜ in. casing was set at 2610 feet, and on December 9th the drilling was finished, resulting in a 650-barrel well at 2621 feet, the total time consumed being 94 days.

In this field there is about 500 feet of hard limestone, found in strata of various thicknesses to be penetrated. From 14 to 20 sets of rock bit cones are used up on each well. Other wells drilled in this field by the rotary have reached 1833 feet in 21 days, and 1950 feet in 24 days, and as formations became better known the drilling speeds were increased. Later on permission was granted to complete the wells with the rotary, resulting in the bringing in of the Tonkawa wells on an average of 45 to 50 days.

The average daily production of the Oklahoma fields in April, 1923, was 478,100 barrels, including the Tonkawa field, prior to the introduction of rotaries.

When the first rotaries were introduced, the production quickly increased, reaching 521,880 barrels per day in June, 1923, a daily increase of 43,780 barrels in two months.

The Smackover Field in Arkansas has also been developed by the

use of the rotary, and the production of this State has progressively advanced, from 34,127 barrels per day in October, 1922, to 77,225 barrels in the following month, and 107,732 in December.

These large and rapid increases were made possible by the rotary system.

Advantages of the Rotary.

The foregoing exposition clearly demonstrates that many of the objections advanced against the rotary system do not now really exist, and every day its many advantages are becoming more thoroughly understood.

The obvious facts in favour of this system are :—

1. High gas, water or oil pressures can be easily and successfully controlled.
2. A more accurate log can be obtained by liberal use of the core barrel.
3. The oil-bearing formations are not subject to continuous penetration by water or mud.
4. Less time is required to complete the well.
5. Less casing is required.
6. Wells are invariably completed at a lower cost.

The Human Element in Rotary Drilling.

The rotary has been introduced during the last few years into many oilfields outside the United States, particularly in Burmah, India, Persia, Russia, Rumania, Poland, Mexico and Central and South America.

In practically every case, particularly in Russia, Rumania and Poland, the decision to use the rotary has been forced on the operating Companies by the failure of, or excessive cost or the time consumed by, the drilling methods hitherto used. In Poland, where hard formations are encountered, and it is necessary to reach depths of about 5000 feet, the Galician or Canadian pole tool system of drilling has proved itself very inefficient, requiring in some cases as much as ten years to reach the required depths. An average time for drilling a 5000 feet well may be placed at not less than five years.

In Persia the rotary system is rapidly displacing the Canadian rig and successfully penetrating very hard formations of gypsum and limestone. One of the rotary wells in Persia has reached a depth of 4220 feet, although the rotary system has only recently been introduced there.

In Rumania rotary wells are finished in from 60 to 90 days, in comparison with the Canadian system's average of 18 months, and the cable tool's average of nine months.

In many fields where the rotary has been introduced in opposition to the existing methods it has been the object of the prejudices of local drillers and engineers, with the result that tests made with the rotary system have often been unsatisfactory. It is essential that the rotary should be operated by competent and experienced drillers. The importance of employing experienced and practical rotary drillers has been demonstrated recently in Rumania. Rumanian drillers operating six rotary machines were making an average of 100 metres of hole per month. In June this year, six highly experienced men were imported and were placed on three rotary machines operating in the same district, with the result the Anglo-Saxon labour averaged 400 metres per month per machine, during the months of August, September and October. So great was the saving they effected in time, overhead, etc., that the comparatively high wages they received became a matter, we must agree, of no significance.

Over half the metreage drilled in Rumania at present is done by the rotary system, whereas in 1913 there was only one rotary operating in the country.

It is gratifying to notice that rotary drillers have now in their ranks many highly-trained young graduate engineers. This will undoubtedly in the course of time increase even to a greater degree the efficiency and results obtained by the rotary system of drilling.

Following are extracts from Bulletin 193 of the United States Bureau of Mines, by A. W. Ambrose, entitled "Underground Conditions in Oil Fields," 1921 :—

"In the past, cable tool well logs have been on the whole much more accurate than rotary well logs, causing a more or less popular distrust of the latter. Rotaries are valuable because they make hole fast, hence the drillers tend to give less care to the formations. One of the real reasons why rotary logs have been so unreliable in the past is the failure to realise the value of good records. Of course, cable tool logs are more reliable, but formations can be determined fairly accurately with a rotary, if proper observations and care is made during the drilling. Hard rock, hard 'shell,' sand (hard or soft) shale and gumbo, can usually be detected by watching the way the engine runs, the action of the rotary table, the 'tune' of the mud pump, and the way the bit wears. There are many examples where formations can be detected by the way they drill. . . .

"The use of a core barrel or drag shoe in sampling formations in a rotary well gives much more satisfactory results. Core samples are obtained at a sacrifice of speed in making hole, but in wildcat territory the loss of time is thoroughly justified, because such samples supply accurate data, which is essential for determining the local position of the oil horizons and for differentiating between formations which aid in drilling and future correlation.

"Very satisfactory work can be done with a rotary when taking cores, and there is no reason for not obtaining good samples as often as may be necessary to determine completely all of the geologic formations. An experience of B. L. Hamilton, consulting petroleum engineer, Houston, Texas, is cited as an example He directed the drilling of two rotary wildcat wells in northern Louisiana. In the first well no core barrel was used and the well was stopped on reaching what was supposed to be the Woodbine

sand, the main producing sand of the Caddo oilfield. In the second well, which is close to the first well, a core barrel was used, and good fossils were obtained which showed that the bottom of the first well was actually several hundred feet above the Woodbine sand. In this work the value of the data obtained with the core barrel obviously more than justified its use."

L. C. Uren, Associate Professor of Petroleum Engineering in the University of California, and one of the foremost engineers in the country, says :—

". . . However, we would not hesitate to undertake the drilling of a well in such a territory with rotary equipment alone, if occasional cores of the formation could be secured with the core barrel."

DISCUSSION.

The President said he was sure the members had been very much interested in listening to the paper which had been read, and seeing the large number of illustrations which the author had exhibited. At the previous meeting of the Institution a great deal was heard about pole drilling, and how the men concerned spent most of their time in fishing, but the rotary drilling system, as expounded that evening, seemed to be by comparison a very simple matter. A good many of those present that evening had had experience in various parts of the world, and it would be interesting to hear of some of the troubles they had encountered, and of how they had overcome them. He hoped anyone who had had such experience would not be shy in relating it.

Mr. Charles Dabell said that his first experience of the rotary system was some twenty years ago in the Caucasus, but the system was not of this particular type. It was a core-producing plant. Cores, 12 inches in diameter, could be obtained from depths down to 800 or 900 feet, and with a 10-inch core the depth could be as much as 1800 feet. They did not find it necessary to use a double-core barrel at all; just a single-core barrel sufficed. The cutter was of the circular type, similar to that which the lecturer had described, the teeth being set one in and one out, thus leaving an annulus between the core and the barrel, about a quarter of an inch or a little more, dependent on the formation. To grip the core they would break up old plates, or flint into the size of a large pea, pump this gently down the rods, and it would then settle around the core. This process was commonly known as grouting, and by this method one got a torsion on the tools and core, and with a sharp snap with the levers the core was broken off and pulled up. That was his first experience with the rotary. He was afraid he had not had much experience with the particular type of core barrel to which the author had referred. The first American Rotary plant that came

into Rumania was in 1909, and the master drillers and himself went up country and drilled down to 1800 or 1900 feet. There the tools got jammed. He remembered how one of the drillers, after tugging and snapping and jerking at everything he could, went off into the woods and asked him (the speaker) to have a try. After various signs and promises of trouble he deemed it wisest to work from behind the boiler, and eventually the whole derrick came down. He was quite prepared to believe that this jamming of the tools did not now take place, owing to the fact that better hoisting gear and tools were in use.

He would like to ask the author of the paper whether mud ever adhered to the inside of the hose or drill-stem, thus decreasing the orifice.

Mr. Campbell M. Hunter said that having had considerable experience in South America in the working of rotaries, he believed the results obtained would be of interest to those present.

The experience to which he referred, had been on the Comodoro Rivadavia Oilfield in Argentina, where the thickness of the oil sands varied considerably, ranging from a few inches to a maximum rarely exceeding 10 feet. When the rotary was first introduced on the Explotacion Nacional de Petroleo, the results were very disappointing, so much so that it was condemned as unsuitable. Some years later it was decided to reintroduce it under better technical conditions. The net result was that while previously wells had taken over twelve months to drill to a depth of about 2000 feet, the first well drilled by the rotary then only took eight weeks, including three weeks necessarily occupied in cementation. The success attaching to the rotary aroused a certain amount of antagonism amongst local drillers, who were using the Fauck drilling system. They maintained that oil sands were drilled through unnoticed by the rotary. It was obvious that this contention had to be disproved, and the following three methods were evolved, each of which satisfactorily overcame the special difficulties, which the formations presented in varying degree in different parts of that oilfield.

In the first method the rotary is used in combination with a hand-rotated percussion system, in which hollow rods and reverse flush are used. In this arrangement, after the well has been drilled by the rotary to the depth at which the water shut-off cementation is effected, the rotary table is removed, a Star machine run in, and drilling with hollow rods, actuated by the latter, resumed. By using the reverse flush, that is, by pumping mud down outside the rods, and getting the return up through the rods, perfect sampling can be effected, and within a few minutes it is possible to tell exactly in what formation the drill is working by the appearance and texture of the little pellets of sand and clay, which are ejected at the surface.

The second method entails the use of a very simple type of split core-barrel which can be made on the property, inserted in a short length of pipe provided with a cutting edge like an auger bit. This core-barrel is attached to the drill-pipe and worked by the rotary. When using the core-barrel the mud circulation is stopped so as not to wash away the core. This arrangement gives excellent results in soft formations, and enables very accurate sampling to be carried out.

The third method adopted is that of stopping the drill every half-metre, and keeping the pumps going for a sufficient time to ensure all sediment being brought to the surface. The mud carrying the sediment is run over a number of casing collars in which reliable samples of the formation are collected. Whenever a change in the formation is noted, the drill-pipe may be withdrawn, the bit removed, a core barrel substituted and more positive sampling carried out as previously described.

As an example of the first method, in one well some 92 samples of absolutely different formations were reported within a distance of 338 feet, the thinnest formation identified being only 6 inches thick.

The combination of the second and third methods in another well gave 55 samples of absolutely different formations within 177 feet, the thinnest again being only 6 inches thick.

One very important advantage results from this way of using the rotary, namely, it enables wells to be drilled with the rotary system in such a way as to minimise, if not entirely prevent, them getting out of control. In the Speaker's opinion the majority of wells get out of control through the driller having unknowingly penetrated the oil sand too deep, thereby upsetting the static condition of the oil sand. The moment static conditions are changed into dynamic conditions, the risk of a well getting out of control is greatly increased, especially when there is high gas pressure.

By using the rotary in combination with hollow rods, as above described, it should be impossible to drill more than a few inches into an oil sand without becoming aware of the fact.

Working on these lines in Argentina, it has been possible to prevent any well getting out of control, even though gas pressures in excess of 800 lbs. have been recorded.

In conclusion, the speaker emphasised the opinion that the rotary, if properly used, was capable of providing very accurate and dependable records of formations penetrated, in addition to being the quickest drilling system at present in use.

Mr. T. Dewhurst said that the paper did not seem to offer much scope for discussion from the geological point of view, but one or two points might be mentioned. Geologists were formerly

opposed to the rotary system, owing to the difficulty of obtaining satisfactory records of the strata drilled through and to the possibility of oil sands being passed through undetected. The introduction of the core barrel had revolutionised the rotary in these respects, and had converted it into the best drilling system from the standpoint of the petroleum geologist. The coring of oil sands was a new feature in the drilling of exploratory wells and geologists were eager to learn what inferences could safely be drawn regarding the value of oil sands from the examination of cores. Thickness and porosity were obviously important features of oil sands, and these, combined with the nature of the oil show given by cores, might enable safe inferences to be drawn as to the probable value of oil sands. Oil sands which were not commercially valuable would probably yield cores with a fair showing of oil. He understood that cores taken in abandoned oilfields proved that oil was still present in large quantities in exhausted oil sands, which not only confirmed the view generally held by technologists that only a portion of the oil in a sand was recoverable by the usual methods of development, but suggested that sands which were not commercially valuable might yield cores with a fair showing of oil. He understood that in the United States the interpretation of core evidence was subject to a wide range of opinion, and he trusted that in his reply the author would throw more light on the significance of the oil indications given by cores. The effect of mud fluid on porous strata seemed to require further discussion. The point which was not quite so clear to him as it was to rotary enthusiasts was that, irrespective of the length and weight of the mud column, and of the pressures in the various gas, oil and water sands encountered, the forces in a rotary well were supposed to be always so balanced that worthless sands were effectively muddied off while valuable sands were never in danger of being adversely affected by the mud fluid. He was much interested in the experiment described by the author in which mud fluid was subjected to a pressure of 400 lbs., and yet formed only a thin film on the rock surface with which it had been in contact. This result agreed with the results of other experiments. For example, in *Oil Weekly*, Vol. 28, No. 9, certain experiments were described, from which it was concluded that the penetration of the mud-laden fluids into the pores of the wall of a well was very slight, and that it was impossible to pump mud back into an ordinary porous formation, the addition of pump pressure merely adding a small amount to the filtered deposit on the wall of the hole. The suggestion that there was no danger of penetration of oil sands by rotary mud-fluid was, unfortunately, not borne out by experience. Kirwan, in discussing abandonment operations of the American Petroleum Company at Well No. 8, Coalinga Field, gave significant data, of which he quoted the following :—

"Evidence that the mud-fluid travelled away from the well when the fluid was thin is had from the fact that muddy water on the fifth day appeared in succession in the production of Wells 7, 6, and 5, being more pronounced in the nearest one, No. 7, distant 332 feet; and least in No. 5, distant 1000 feet."

Again, Nolan cited an abandonment job in the East Side Coalinga Field, where over 40 tons of mud under a pressure of less than 200 lbs. were pumped into a 30 ft. sand, and three days afterwards appeared in a well 400 feet away. Furthermore, circulation was sometimes lost during rotary drilling, and appreciable quantities of mud obviously disappeared. Surely when this happened the mud formed more than a film on the wall of the hole? In case it should be contended that the mud fluid was probably thin in all the examples referred to, he gave a case which recently came to his notice. Of two wells, situated 134 feet apart, one was producing oil and the other was being drilled by the rotary system. The mud-fluid used in drilling this well was as thick as the pumps could handle, being 14 lbs. to the gallon. The mud circulation became unsatisfactory for 24 hours, and was then entirely lost, the top of the mud-fluid column being 150 feet from the surface. The owner of the first well then reported that his well had been completely muddied up and that only mud was being pumped. Therefore, although experiments showed that mud-fluid would merely form a thin filtered film close to the surface of a porous formation, the examples he had mentioned showed that mud-fluid, and even very thick mud-fluid, could and did travel, probably along joint planes in sandstones, and possibly along induced drainage channels in sands, for considerable distances, and even from well to well. In such circumstances he thought that the author should offer evidence for his statement that it had been conclusively demonstrated that the danger of oil levels being flooded by rotary mud was a theoretical rather than a practical one. One further point: he knew of several rotary drilled wells which had given excellent showings of oil while drilling through known productive oil sands, but which had failed to give any production from these sands after thorough washing with clean water and subsequent bailing. It seemed possible that in these cases the rotary mud-fluid has formed more than a thin superficial film on the surface of the oil sands, and had even formed a thick annulus of mud-laden sand, which could not be removed by subsequent washing with clean water. He hoped that the author would enlighten them on these points in his reply. He was in complete agreement with his views on the enormous advantages of modern rotary drilling in regard to speed, economy in casing, and the use of the core barrel.

Mr. J. C. Templeton said that it was to be regretted that in

dealing with this important subject the author has done so as an obvious enthusiast, and has allowed his enthusiasm such scope as has prevented the dealing with certain generally known disadvantages of this particular method of drilling to any noticeable extent.

The danger is, of course, the possibility of the inexperienced taking the conclusions of the author at their face value, and it is with the purpose of placing the other side of the picture before members that the following remarks are made.

Insufficient data is given whereby members can draw their own conclusions, and when comparative results are given, sufficient particulars of all the relative circumstances should also be appended.

The author, in commenting on the supposed danger of flooding oil horizons in using the rotary mud flush, states that the danger is a theoretical one. He also goes on to say, with reference to the use of the "Combination System," that by using the core barrel it is easily possible to calculate the underground features, and do away with the cable tool feature altogether. He asked if the author advocated the use of the core barrel all the way when once started, or whether he considered the periodic use to be sufficient for all purposes? His (the speaker's) opinion was that when considered desirable to introduce the core barrel in rotary work, the coring should be continuous, generally speaking. In any zone where there is the possibility of porous formations existing, to take cores on the periodic system gives a geological profile with gaps, which gaps might obviously contain the evidence the geologists were looking for, or might be the means of passing an oil or gas horizon.

To infer, as the author does, that the passing of porous formations, or the flooding of such, is only a theoretical and not an actual danger of the rotary system of drilling, is in contradiction to the general experience of the industry. It should be generally recognised and emphasised that any kind of porous formation is capable of storing oil and gas. The quickest and surest means of identifying the various formations passed through should be one of the principal objectives of any drilling system. Having once identified a porous formation, particularly with a mud flush system, the only conclusive method of testing is by bailing.

As is well known, the rotary operators abhor all bailing operations, as obviously it means setting the casing and the possible loss of this particular column. The great tendency of rotary drillers is therefore to bail only where they consider they have a very strong show of suitable formation or indications of oil or gas. Such tendencies are most dangerous in all drilling work, but particularly in exploration operations. It is this dislike for bailing which has, to some extent, been responsible for the passing of what have eventually proved to be oil horizons.

Criticism of the author's conclusions might be grouped under the following headings :—

(1) The possibility of passing porous formations unobserved.
(2) The possibility of flooding or sealing productive oil or gas horizons.
(3) Reliability of samples of cuttings obtained from rotary drilling.
(4) Reliability of water shut-off operations under rotary drilling conditions.
(5) General statements concerning the rotary results obtained in the Californian fields.

(1) The passing of porous formations is easily possible, owing to :—

(*a*) The almost impossible degree of care and watchfulness necessary on the part of the driller, thereby increasing the extent to which the human element enters into the result, as compared with other systems of drilling.
(*b*) The tendency of cuttings from porous formations to become so mixed with the mud-flush as to be confused with sandy marl or similar mixed formations.
(*c*) The effect of the tendency of cuttings to fall back whilst being borne upward by the mud-flush. Also the variations of this tendency according to the particular quality of the mud-flush being used at the moment.
(*d*) Owing to one of the objectives of rotary drillers being the making of hole, and with as few columns of casing as possible unless the show of porous material is of considerable consequence, the troubles and attendant difficulties of bailing will not likely to be incurred.

(2) The possibility of flooding and sealing oil or gas formations :—

Amongst the many advantages claimed for the rotary system is the ease and ability with which any troublesome gas or water formation can be sealed-off. Therefore, to the same extent that it is an advantage in sealing-off troublesome formations, so must it be a disadvantage in the case with which possibly productive horizons can be inadvertently sealed-off. Here again, the only possible means of minimising this tendency is to bail on the slightest evidence.

(3) Reliability of samples of cuttings obtained from rotary drilling :—

There are several factors involved in the production of samples of cuttings by the rotary, and in the bringing of them to the surface, *viz.* : (*a*) action of the pump ; (*b*) velocity of mud-flush, which, in

itself, changes with the size of the bore, and the size of the drill-pipe ; (*c*) speed of drilling ; (*d*) rotation of tools ; (*e*) the lag of the cuttings.

The driller is required to recognise the effect of each of these factors on each change of formation. Here again the extent to which the human element enters into the result which goes down in the well log is much greater than with other drilling systems. The rotary is far from accurate in recording the changes of formation, and is certainly very much behind other systems in this important feature.

A number of cases within his experience lead to the above opinions, but in preference to giving these it would be of more value to the discussion to quote from and refer to a recent publication of the U.S. Bureau of Mines, Bulletin No. 201. This is the most comprehensive and convincing publication which he had read, dealing with the merits of the various systems of drilling over a large area. It is also rather a coincidence that most of the examples of the limited usefulness of the rotary system are based on the results obtained from the Californian fields. The author also bases his opinion of the universal usefulness of the rotary outfit on the results obtained from the same fields.

In the aforementioned bulletin a table is given on page 65 showing that a cable outfit recorded 73 changes of formation, as against an average of 36 changes recorded by three rotary-drilled holes in the same area.

(4) Reliability of water shut off operations under rotary drilling conditions :—

On page 67 of this bulletin, Table No. 8, is shown a comparison of the cable *versus* rotary, in connection with the shutting-off of water. As the result of the study of 814 water shut-off operations the cable showed 14·4 per cent. failures, whilst the rotary showed 21·8 per cent. failures.

The bulletin goes on to say that, with reference to the results quoted, " in the important matter of correctly finding suitable formation in this strata to shut off water, rotary failures are undoubtedly due to discrepancies in measuring depths in rotary holes with drill-pipe, or to inaccurate logging of the depths of formation changes, or to the impossibility of bailing hole, during drilling, to identify oil- or water-bearing strata."

Fig. 5, page 69, gives stratigraphically equal parts of graphic logs of two wells drilled in a California field, one with cable and the other with rotary tools. In summing up on the results the article states " it would be impossible to correlate (referring to a formational marker, 2187 to 2225 feet, in the cable-tool log A) this stratum, or any other stratum, with formations shown in the rotary log B." This comparison is stated to be *not exceptional*.

The reasonable conclusion that can be drawn from the above comparisons is that changes of formation are not recorded in the rotary-drilled hole with anything like the same accuracy as in the cable-tool hole, and therefore, the fact of not having an accurate log of the formations is bound to produce difficulties and miscalculations in selecting the most suitable point to shut off water.

(5) General statements concerning the results of the rotary drilling system obtained in the California fields :—

The whole tone of the paper is that the rotary system has been proved to be capable of almost universal application, also that the objections raised are unimportant and more theoretical than practical in their nature. This opinion is apparently based on the results obtained on the California fields; yet Bulletin No. 201, which justifies fully the opinion of limited usefulness held by many experienced engineers, bases its conclusions principally on the very complete and detailed observations made on the same Californian fields by the observers of the U.S. Bureau of Mines.

There is no doubt that, whilst the rotary system is very advantageous in many areas under certain well-defined circumstances, it is nevertheless a positive danger in exploration work, and also in areas where lenticularity of the productive formations exists.

It might be the reply of those who favour the author's views that the use of the core barrel in conjunction with the torary method overcomes all the disadvantages mentioned. In a number of the objections this is so, but not in all, and only provided the core barrel is used continuously from start to finish of drilling in exploration work; and continuously below definite key horizons in all proved territories. If, on the other hand, coring is carried out only periodically, then it should be made perfectly clear that there is absolutely no certainty that the evidence sought has not been passed in the gaps during which no cores have been taken.

If, in exploration work, continuous coring is essential over great depths, then the great saving of time claimed for the rotary system will be entirely wiped out. So that in this class of work drilling by rotary means :—

(*a*) Greater initial cost in purchasing the outfit; and (*b*) Greater operating costs, since it costs more to operate a rotary on a time basis than with any other system.

The one outstanding advantage still remaining is the saving in casing, but in this connection, if each porous formation met with is tested properly, there would be fewer smaller claims regarding casing saved. It is false economy to make record drilling times and great savings in casing, at the expense of running the great risk of passing paying oil or gas formations, or passing other important geological features unobserved.

Mr. T. G. Madgwick said that he had one criticism to make, and that was that the author attributed the rotary system to Fauck. The original water-flush system was usually known as the Fauvelle, the actual inventor of which was an Englishman named Beart, and Fauvelle the engineer who designed the plant. The principle of the Fauvelle system was both a rotary and percussive, and from those two varieties of action there had been evolved, on the one hand, rigs of the Fauck type, and, on the other hand, those like the present rotary. The Fauvelle was originally used in France, but in the Chalk there it was not a very great success, owing to difficulty in keeping the water; moreover, the mechanical side of drilling was only in embryo at that time. Then in 1855 he believed it was adopted in Denmark for drilling for water through alluvial and glacial drift, and thence it was transferred to the States, where it had a very extended use, mainly in drilling in the alluvial valleys of the big rivers. In the *Engineer* for 1885 an interesting article by Darley would be found describing what was clearly the predecessor of the present rotary. The name especially associated with its subsequent development is that of Chapman, in whose hands it took the form which was first applied to oil by Col. Lucas at Spindle Top. Thus the rotary system was evolved purely for water drilling, even down to the mud flush, and oil people therefore had had little to do with its development so far as principle was concerned; great credit should be given to American mechanica engineers, who overcame the difficulties which confronted them in its application to the needs of oil-well drilling.

Mr. L. R. McCollum, in reply, said in answer to Mr. Dabell's remarks regarding the adhesion of mud on the inside of rotary hose and drill-pipe, this has never been perceptible. The opening or orifice in tool joints, drill collars, hose swivel, etc., or tools making up the drilling string, does not exceed 2½ inches, whereas the opening in the fish tail bits through which the mud laden fluid is ejected, is three-quarters of an inch in diameter, and, as stated above, the adhesion of mud fluid is not perceptible.

The remarks of Mr. Campbell M. Hunter, on his experience with the rotary in Argentina, are extremely interesting and demonstrate fully the necessity of adapting the rotary to each particular or peculiar condition.

With regard to the question raised by Mr. Dewhurst, as to the interpretation of evidence formed by cores, the knowledge at hand at present does not make it possible to give definite reply to his query in regard to the absolute value of cores in a new or wildcat venture. In using the evidence from cores in fields where the general depth of the oil-sands and the oil and gas content of the different horizons are known factors, the core can be depended

upon as a very definite and valuable evidence. In contrast to such conditions; if the core is in a wildcat well or a new structure, the evidence is perhaps less reliable, but all geological evidence as to structural conditions, thickness and porosity of sands, etc., is only relative evidence, depending upon whether or not oil and gas actually exists in the sands in commercial quantities. A geologist can say a structure is favourable, but it is for the drill to prove it; it cannot be said that oil is there for a certainty until evidence is furnished by the drill. With a large expenditure of capital an operator should be more than anxious for every scrap of concrete evidence. Accordingly he must interpret his cores and make his own deductions. This is true of all evidence from a hole. The oil-sands are studied, and, if doubtful, given chemical tests.

It is impossible in a paper of this nature to make limiting statements as to which cores would represent pay sands, and as to which would not be of commercial value, as there are many contingent factors to be interpreted, such as depth, thickness, porosity of sands, character and quality of oil and gas pressures, the mixture or density of the circulating fluid, etc., but all of these things should be carefully weighed and studied, and the human element, and we might say the supervision, should be of the very best.

Further commenting on Mr. Dewhurst's query as to the effect of mud fluid, this further emphasises the need of the core evidence, plus a decision—yes or no—as to the value of the formation under observation. If it is decided that it is worthy of a test, it should not be muddied off; if not, drilling is slowed down, and mud is thickened and circulated until this particular formation is thoroughly muddied off. If there is evidence, the usual procedure towards making a test is brought into play.

Mudding off a sand in drilling operations necessarily involves a time factor and is contingent entirely upon the treatment of the formation by the operator. In the hands of an inexperienced driller there is always danger of mudding off a valuable formation, and numerous incidents are on record where territory was drilled and "turned down," when in later years this field was brought into production by a properly conducted exploitation.

Likewise we know of similar instances where drilling with the cable tools with a hole full of water, oil-sands were passed up. We cite, for example, the Bardsdale field in Ventura County, California. The initial wells in this field were drilled with a hole full of water, the operators finding the work progressed more favourably where the caving formations were held back by the static pressure of clear water. Later, however, drilling with cable tools in a dry hole was undertaken and formations which, when drilling in this district with a hole full of water, bore practically no evidence of containing light oil, were found to be excellent producers.

It must be borne in mind that a delicately balanced operation, such as mentioned by Mr. Dewhurst, is worthy of careful handling as large sums of money are at stake. In contrast to the need of the efficient conducting of oil operations, mining may be cited where, with the expenditure of as little as from five to ten thousand pounds, elaborate preparations are made, expert mining engineers are employed, blue prints and engineering data are provided, and the work is conducted in the most careful, scientific manner, whereas in the drilling of oil wells, too little consideration is given to the supervision, the expert advice and careful management.

Evidence of the "Circulation of Mud Fluids," as mentioned by Mat Kirwan, concerns old wells which have been producing for many years and have, moreover, been flooded by careless water shut-offs; if not in the particular wells mentioned, certainly in neighbouring wells. In truth, it is a water migration and not an oil sand penetration, as there was no oil in the sands under gas pressure to resist water movement—in fact, water had undoubtedly opened numerous flood channels in the formation referred to. In addition it will be interesting to know that in the specific case mentioned by Mr. Kirwan there were heavy exhaustions of oil sands during the producing life of the wells. It is common knowledge that during the first six or twelve months these wells gave from 20 to 30 per cent. in the oil.

Likewise Mr. Nolan's comments relative to *abandoning* jobs, is merely another case of endeavouring to fill voids made by previous extraction of tons of oil and oil-sands, and quantities of gas, to say nothing of the invasion of water. I desire to reiterate my previous comments—that danger of oil levels being flooded by rotary muds is a minimum danger on new fields, and is entirely possible on old gas-pressure exhausted fields, but in the latter case the moving water factor is usually so predominant that when large quantities of water are again lifted from the well, the mud introduced will be washed out. I accordingly admit that in cases where the resistant oil or gas pressure is such as to readily admit the mud, caution should be used in the method of handling the circulating fluid, and in many instances the abandoning of old wells in old exhausted fields should be carried out by a dry method of drilling, should the conditions mentioned by Mr. Dewhurst prevail.

I presume he has referred to old fields, and bear in mind that all development in every sort of drilling is progressive, and subject to improvement and to rational interpretation of the problem in hand. My object was to cover the trend of development of the art of drilling with the rotary system, and to cover the factor encountered in drilling 90 per cent. of all wells, but I must frankly admit that freak conditions are continually met with in isolated wells and fields.

Referring to Mr. Templeton's first question on the use of the core barrel, the writer agrees that the ideal way to test any wild-cat district or unknown territory is the liberal use of the core barrel all the way—in fact, a one hundred per cent. core. But this procedure is rarely necessary, and not always possible or practicable. We must assume, in the first instance, that most wild-cat tests are being conducted on the advice of a competent geological staff, and, therefore, the various sands and thicknesses of strata, together with faults, dips, ages, etc., have been more or less determined, and the horizon most likely to contain petroleum has generally been calculated within a few hundred feet. Therefore, the overburden or upper formations are generally unimportant, and have no practical value.

When a depth is reached where the geological report indicates oil possibilities, the core barrel can be brought into play at each new change in the formation. Experienced persons are able to determine immediately the slightest change.

The core barrel properly employed, as described in the original paper, would, and does, promptly indicate where it is desirable to set casing and make a test by bailing.

The possibility of flooding and sealing oil or gas formations, is covered in reply to Mr. Dewhurst's remarks.

Reliability of Samples.—The principle brought into play by the rotary is, from an engineering point of view, the most logical and, one might say, the only logical method of boring a hole. In all branches of industry holes are bored in wood, iron, steel, etc., by a rotating or rotative action applied to a special bit, drill, or tool, and the substance drilled in this manner is forced out of the hole in clean, though in some instances, small perfect specimens.

What applies to engineering practice in drilling substances infinitely harder than 95 per cent. of the formations encountered in drilling the earth's surface, must necessarily be true in drilling for oil.

With the use of the mud-laden fluid in conjunction with rotary drilling, in theory and in practice, the formations drilled are displaced by a formation in solution, a formation of our own making. This same soluble formation—a mud-laden fluid, the character and consistency of which is carefully regulated and maintained—acts as a conveyor or lift, and brings to the surface the samples of every formation encountered in amply large and perfect segments.

There is no pounding, pulverising or distorting influence applied to the formation with the rotary, as in the case of the percussion tools, except in the use of the roller bit, which acts and operates as a milling tool. However, this particular tool is used on granite, lime and similar hard formations in which oil is seldom or ever found.

Therefore, *with proper supervision*, and the employment of vigilance, with the driller noting each change in the formation, actual and perfect samples of each strata drilled can be easily secured.

After the first well is successfully drilled under painstaking supervision subsequent wells are put down with the rotary to the final water shut-off, in rapid time and at a great saving in time, casing and money.

While Bulletin No. 201, prepared by the U.S. Bureau of Mines, deals largely with conditions in California at a time when the rotary was drilling from 25 to 35 per cent. of the wells only; to-day, 95 to 97 per cent. of all wells are drilled with the rotary system, and the obvious conclusion one must draw is that the rotary has overcome its many objections, or at least its advantages have greatly overshadowed the advantages of the percussion tools, both as to the sampling of formations and locating successfully oil-bearing strata and the proper shutting-off of water.

All water tests in California in very recent years are made under the supervision of the State Petroleum Department Engineers, and no well is completed into the oil sand unless a perfect shut-off has been effected, which is as it should be.

The present-day use and application of the rotary system of drilling has developed many remarkable features in the last twelve months, and the paper touches in a brief way only on generalities in their widest application. Improvements in tools and practices are very rapid, and it is hoped that in the succeeding twelve months even the more specific "problems," such as were brought to light by the several criticisms submitted, will be met with and overcome.

The President said that he was sure the Institution was greatly indebted to Mr. McCollum for his very interesting paper, and it was his duty to ask those present to accord a hearty vote of thanks to him.

The vote of thanks was accorded by acclamation, and the proceedings terminated.

Mr. R. V. Wallis subsequently wrote:—I am afraid that an erroneous impression will have been created in the mind of a layman, both that the rotary system has overcome all defects of other systems, and that, provided the operators be experts, actual drilling by that system is mere child's play. Surely it is a weakness to judge a system only on results obtained in California, where it is not so much a question of experts, as specialisation, with the adopted practice there of distinct casing crews, fishing crews and coring crews. The lecturer admits failures outside the U.S.A., which he ascribes to *incompetent handling*, but surely the outfits in question were run by *selected* American drillers.

The author states in his paper that fishing jobs are few and simple, but I do not think that that statement will be corroborated by managers on foreign fields.

A slide of a rotary underreamer was also shown. I should be indebted to the lecturer if he would kindly state when this tool was successfully tried out, and on which fields it is now adopted.

Regarding the use of several drilling collars, the lecturer spoke of increasing the weight on the bit—surely it is rather a matter of keeping a certain proportion of the weight off the bit?

Regarding coring and bringing-in wells with the rotary surely this was another case of inverted figure of speech? I understand that coring has had to be adopted, and subsequently specialised in, in order that the Californian wells may be brought in by the rotary, a necessity consequent on their great depths, *the position of the producing sands being also approximately known*. Also do not most of the companies employ contractors or special crews for taking cores as the drillers there, presumably expert, cannot be trusted to do that work satisfactorily?

I certainly cannot agree with the first three of the obvious facts, in the lecturer's summary, in favour of the rotary system, unless in

(1) he uses "controlled" in the sense of "drowning" only.
(2) He refers only to such fields where one can contract-out for coring with specialists in that work.
(3) He refers only to the new, to me, and interesting data he gave us concerning the "use of mud-laden water in drilling wells."

By way of postscript I quote from a paper read at a Meeting of the Institution on January 15th, 1918, *viz.*:—

> "It is evident from what has been said that no one (drilling) system can be generally advocated for Rumania, each system having its advantages and disadvantages. Before selecting the plant for drilling in an already exploited field, existing data suffice to ensure the best choice. In unexplored fields the percussion system is advisable, as the operator is very often unacquainted with the characteristics of the rock to be drilled."

In replying to the above Mr. McCollum wrote:—I wish to point out that the entire trend of my paper was to depict the progress made in the evolution of rotary drilling methods, and in the development of the art. The necessity of having trained and experienced men to handle the tools and equipment of very great weight with speed and accuracy, is more apparent. The modern rotary is not a fool proof invention, and the more efficient and capable the human element, the more satisfactory and sure the results.

In California, in the Mid-Continent fields, and in the Southern

Texas, Louisiana and Arkansas fields, there are very few failures in connection with rotary drilling—in fact, were it not for the rotary system the last three districts would never have been developed.

The formations throughout the Mississippi Valley are alluvial and extremely caving, and no percussion system is known capable of coping with these formations. The failures in foreign fields are very small—in fact, there are over fifty rotary outfits operating in Rumania, and only three are manned with experienced American drillers, and fifty per cent. more holes were actually drilled in Rumania in 1923 than in any one previous year.

The question of proper weight to be used on a bit during the process of drilling, is not at all affected by increasing the number of drill collars. By using long drill collars, or a combination of drill collars, a greater rigidity is produced and sufficient weight is provided on top of the hole where weight is actually required.

The use of casing crews for setting casing, is confined almost altogether to Mid-Continent fields, in conjunction with contractors in the employment of the cable system. No instance is known where, in rotary drilling, a special crew to insert casing was employed. Very large operating companies who are running a great number of strings of tools may find it more efficient to employ casing crews for this purpose, but certainly a small operator depends entirely upon the rotary crew to insert the pipe.

The coring of wells has been practised since the early Spindletop days. Core barrels were made by the driller from an ordinary casing shoe, the bottom of which was worked over with a hack saw into a series of staggered teeth, laterally tempered. This shoe was run into the hole on the bottom of the drill-pipe, and adamantine or chill shot was introduced in the circulating fluid. By this means it was possible to drill through lime formations with the rotary. In fact, prior to the development of the roller rock bit, the saw tooth rotary shoe was universally employed. In every instance this was operated by the rotary driller, no specialist being required or employed.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE SEVENTY-FIFTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts on Tuesday, January 8th, 1924, Mr. H. Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A. (President) occupying the Chair.

The President, in opening the meeting, said it was unnecessary for him to introduce the authors of these two papers, as they were both so well-known; and that the discussion on both papers would be taken together.

The following papers were then delivered by Mr. James Kewley and Dr. A. E. Dunstan:—

The Crude Oil of Sarawak.

By JAMES KEWLEY, M.A., F.I.C., F.C.S. (MEMBER).

SARAWAK CRUDE OIL.

THE commercial development of the oilfields of Sarawak dates only from 1911, in which year only 170 tons were produced. Production, however, has steadily increased particularly during the last two years.

PRODUCTION OF CRUDE OIL FROM SARAWAK.

1911	170 tons.	1917	75,458 tons.
1912	5635 „	1918	68,629 „
1913	26,067 „	1919	81,739 „
1914	64,503 „	1920	141,492 „
1915	66,845 „	1921	199,856 „
1916	88,499 „	1922	403,394 „

The present weekly production of the fields amounts to about 11,000 tons. This places Sarawak second on the list of producing countries included in the British Empire. This fact, together with the rather peculiar nature of the crude oil and the possibilities of future developments and applications, justifies this further short

paper on this subject, which the author briefly dealt with in a previous communication (Crude Oils of Borneo, Journ. Inst. Petr. Techn., Vol. VII., p. 209, pt. 27, July, 1921). These oils are by no means well known in comparison with those of the East Borneo fields, so that so far few, if any, investigators have turned their attention to the subject. The crude is, so far, produced in the Miri area, about 150 miles south of Brunei Bay. It occurs in sands of Miocene age, which are folded into a well-marked anticline which is characterised by a series of minor faults and small overfolds. Oil has so far been found at all depths, down to about 2000 feet, the deepest level so far worked. The character of the oil is, as far as yet observed, generally uniform, but there is a distinct change in specific gravity with increase of depth, the lighter oil being found at greater depths, as is also the case in the Koetei fields of East Borneo.

The oil is of the naphthenic type, but the recent appearance of a paraffin base oil at about 1950 feet leads one to suspect that, as is the case in East Borneo, wax-bearing oils may be characteristic of the lower levels.

General Characters of the Crude Oil.

The crude is a mobile liquid, reddish brown in colour, and of agreeable odour. A sample of the mixed crude oil, as recently worked up in the Lutong Refinery, gave the following data on analysis :—

Specific gravity at 15° C.	0·902
Refractive index at 15° C.	1·5075
Iodine value	12·8
Hard asphalt, insoluble in petroleum ether	Traces.
Paraffin wax	Trace.
Ash	0·01%
Conradson coking value	0·64%
Flash-point, Abel	61° F.
Viscosity Redwood 1 at 70° F. (21° C.)	41 seconds.
" " 1 at 100° F. (38° C.)	36 "
Calorific value	10,760 calories per gram
Pour test (A.S.T.M.)	Below –37° C.

Elementary Analysis.

Carbon	86·47%
Hydrogen	12·37%
Nitrogen	0·13%
Sulphur	0·35%
Oxygen (by difference)	0·68%
	100·00

Distillation in Engler Flask (temperatures not corrected for emergent stem).

Initial boiling point	.. ..	97° C.	
Boiling up to	100° C.	0·5%	by volume.
„ „	125° C.	2·5	„
„ „	150° C.	9·0	„
„ „	175° C.	18·0	„
„ „	200° C.	23·0	„
„ „	225° C.	31·0	„
„ „	250° C.	41·0	„
„ „	275° C.	53·0	„
„ „	300° C.	65·0	„

From the foregoing it will be seen that the crude is deficient in fractions of low boiling point. It is free from paraffin wax, naphthenic in character, and remarkably free from asphaltenes. It has very low viscosity, low sulphur content and yields products which are easily refined.

The above analysis represents that of an average mixture of the crudes as produced.

The crudes from different wells display a good deal of variation in character, although the general type is the same throughout.

The following table illustrates the variation in character with depth :—

Miri Field.

Depth.	Sp. Gr. at 15° C.	Vol. % boiling to 150° C.	Vol. % boiling to 200° C.	Vol. % boiling to 250° C.
400 feet	0·948	—	—	7
500 „	0·932	—	7	25
1000 „	0·857	29	42	55
1400 „	0·852	38	49	61
1900 „	0·828	30	41	53

Pujut Field.

Depth.	Sp. Gr. at 15° C.	Vol. % boiling to 150° C.	Vol. % boiling to 200° C.	Vol. % boiling to 250° C.
120 feet	0·955	—	—	1·5
350 „	0·949	—	—	7
1000 „	0·914	—	11	33
1300 „	0·910	—	7	26
1300 „	0·893	—	26	44
1400 „	0·897	—	22	43

The variation in character of the crude is well marked.

Other isolated examples of variation from the normal type are :—

Specific gravity at 15° C.	0.797
Boiling up to 100° C.	6%
„ „ 150° C.	35%
„ „ 200° C.	50%
„ „ 250° C.	64%

and

Specific gravity at 15° C.	0.865
Boiling up to 300° C.	35.5%
Paraffin wax in residue over 300° C.	20%

These two oils represent only shows. At the lowest levels, almost 1950 feet, an oil containing 3·8 per cent. of paraffin wax occurs. A more complete distillation test on the crude oil carried out in a four-gallon still, fitted with live steam coil and steam superheater, but without any fractionating column, gave the following data:—

Fractions 5% Volume No.	Sp. Gr. at 15° C.	Refractive index at 15° C.	% Sulphur.
1	0·775	1·434	0·026
2	0·795	1·442	0·024
3	0·804	1·447	0·03
4	0·820	1·456	0·035
5	0·836	1·467	0·035
6	0·843	1·469	0·045
7	0·866	1·481	0·055
8	0·879	1·490	0·06
9	0·890	1·497	0·065
10	0·900	1·502	0·075
11	0·907	1·508	0·085
12	0·914	1·516	0·10
13	0·922	1·521	0·11
14	0·933	1·527	0·13
15	0·947	1·534	0·15
16	0·961	1·542	0·15
17	0·975	1·549	—
18	0·994	1·561	—

The residue is a brittle dark brown resinous looking body of melting point 107° C.

DISTILLATION TESTS OF FIRST FEW FRACTIONS. A.S.T.M. METHOD.

Fraction No.	I.B.P.	10% at	30% at	50% at	70% at	90% at	F.B.P.
1	72	94·5° C.	106	118	136	185·5	222
2	95	108·5	121	136	159·5	211	261
3	104	117	129·5	148·5	176·5	222·5	269
4	115	131	146	165·5	190·5	234	282
5	135	151	167	187	211	247	288

From the foregoing it will be noted that the specific gravity of the fractions is decidedly high in comparison with those of fractions of similar boiling range from the more usual types of crude oil. The same applies to the refractive indices. The sulphur shows the usual distribution, the percentage being higher in the fractions of higher boiling point; the percentage in the lower boiling fractions is distinctly low.

Chemical Characters of the Oil.

The elementary analysis of the crude shows the C/H ratio to be high. No attempt has yet been made to isolate any individual hydrocarbons, or even to get any evidence as to the actual nature of the hydrocarbons which make up the bulk of the crude. The difficulty of doing this is only too well known. It is only in the case of the most volatile fractions that we, so far, have any definite information. An examination of a Miri benzine of final boiling point 200° C. showed 5 per cent. of aromatics, the balance being almost entirely naphthenes. A more volatile benzine with final boiling point 150° C. showed aromatics about 2 per cent. and naphthenes about 86 per cent. One still more volatile of specific gravity 0·743, and final boiling point 125° C., showed 1·7 per cent. aromatics, and 58 per cent. naphthenes. The practical absence of paraffins except in the most volatile fractions, is noticeable. Negative bromine and iodine values indicate the absence of unsaturated hydrocarbons, at any rate in the fractions of relatively low boiling points.

Of the chemical composition of the higher fractions nothing is definitely known. From the relatively high specific gravities of the fractions it may be inferred that paraffins are conspicuous by their absence.

The following table gives the specific gravities of fractions taken at various temperatures:—

Temperature of Vapour.	Volume per cent.	Sp. Gr. 15° C.
Up to 120° C.	2·6	0·754
From 120 to 140 ..	3·3	0·767
„ 140 to 160 ..	6·7	0·778
„ 160 to 180 ..	8·0	0·794
„ 180 to 200 ..	6·9	0·814
„ 200 to 220 ..	6·9	0·833
„ 220 to 240 ..	6·0	0·856
„ 240 to 260 ..	6·8	0·878
„ 260 to 280 ..	10·3	0·896
„ 280 to 300 ..	7·1	0·913

The specific gravities of these fractions are almost as high as those of fractions of similar boiling range from the aromatic crudes of East Borneo. The Miri kerosene fractions are, however, probably mostly naphthenic rather than aromatic, since in spite of their high specific gravities they give a kerosene which will burn in an ordinary lamp, although the flame is of a slight reddish tint and has a marked tendency to smoke. The gas oils and residual oils are normal naphthenic oils. The residual oils resemble rather filtered residues, in that they are distinctly green in colour and contain no hard asphalt insoluble in alcohol ether. Their Conradson coking value is also very low, about 0·7 per cent.

If a sample of Miri fuel oil be submitted to further distillation with steam in the ordinary way, a series of distillates ranging from gas oils to heavy lubricating oils are obtained.

A sample of Miri residue of specific gravity 0·945 and flash-point 79° C., yielded on steam distillation the following fractions :—

	Fraction.				
	1.	2.	3.	4.	5.
Percentage yield ..	5·1	7·3	4·9	2·7	5·3
Sp. gr. at 15° C. ..	0·951	0·968	0·988	0·996	0·998
Flash-point, ° C. ..	130	157	184	199	205
Viscosity, Engler—					
At 20° C.	4·75	16·70	—	—	—
At 50° C.	1·74	3·08	10·05	20·6	133
At 100° C.	—	—	1·82	2·20	3·14
Flow-point, ° C. ..	below —10	below —10	—20	2	15

In general these oils are characterised by rather lower flash-points and higher specific gravities than one usually associates with the corresponding viscosities.

The lubricating oil distillates are remarkable in that they are of good odour and colour and that they retain their odour and colour practically unchanged on standing. In consequence of this they can be easily refined with little loss to oils of very good appearance. For example, an oil of viscosity 5° Engler at 50° C. was refined to a pale orange colour, using only 3 per cent. of acid, with a refining loss of only 7 per cent. If the distillation be carried on until the residue amounts to only 8 per cent. or so of the crude, the last distillates obtained are rather curious substances, as is also the residue. The heaviest distillates are very largely soluble in absolute alcohol, a rather unusual phenomenon. They also nitrate readily, giving nitro-compounds which have, so far, not been examined.

The behaviour of Miri fuel oil with formaldehyde points to the presence of unsaturated cyclic hydrocarbons, as it was found that the fuel gave a very high formolite test, so that after three successive treatments the oil still gave a precipitate with formaldehyde. On the other hand, the opposite would be inferred from the low iodine value of the oil. It is very evident, therefore, that Miri crude will afford a very interesting field for research.

Products from Miri Crude Oil.

Benzine.—An unrefined benzine of final boiling point 200° C., amounting to about 14 per cent. of the crude oil had the following properties :—

Specific gravity at 15° C.	0·786
Refractive index 15° C.	1·439
Sulphur	0·028%
Copper corrosion test A.S.T.M.	Negative.
Unsaturated hydrocarbons	Absent.
Aromatic hydrocarbons	About 5%
Naphthenes	Over 90%

DISTILLATION TEST, A.S.T.M.

Initial boiling point	80° C.
4·5% at 100° C.	
10% at 108° C.	
30% at 122° C.	
50% at 136° C.	
70% at 152° C.	
90% at 174° C.	
Final boiling point	200° C.

The chemical composition of the benzine fractions is reflected in the behaviour of the product in a motor engine. A benzine of specific gravity 0·796, boiling between 100° C. and 230° C., on being tested in a variable compression engine was found to withstand a compression ratio of 5·3 to 1 without appreciable detonation, a remarkable result in comparison with that given by benzines largely composed of paraffins, with 40 or 50 per cent. boiling below 100° C. In practice such benzine is blended with casinghead gasoline made from the rich gas of the North Sumatra fields. This benzine requires no refining, resembling in this respect the benzines of the Dutch East Indies.

Kerosene.—The type of kerosene made depends naturally on market conditions and demands. Owing to the abnormally high specific gravity of the Miri distillates a kerosene of the normal boiling range, say 150 to 290° C., would have a very high specific gravity. The type of kerosene usually made has the following properties :—

Specific gravity at 15° C.	About 0·850
Sulphur	0·05%
Boiling up to 150° C.	8%
„ „ 200° C.	45%
„ „ 250° C.	75%
Final boiling point	277° C.

The burning qualities of such a kerosene are not good, but are better perhaps than might have been expected for an oil of such high specific gravity.

The *Fuel Oil* resulting as a residue after the removal of the benzine and kerosene distillates is a mobile oil of low setting point, having the following properties :—

Specific gravity at 15° C.	About 0·930
Flashpoint P.M.	165° F.
Viscosity Redwood I. at 70° F.	75 seconds.
" " at 100° F.	49 "
Pour test, A.S.T.M.	Below −20°C.
Sulphur	0·4%
Ash	0·01%
Conradson coking test	0·7%
Hard asphalt	Traces.

This residual oil is thus in every respect not only a good fuel for furnace work, but for Diesel engine use, too.

An elementary analysis of another sample of Miri fuel showed :—

Carbon	87·25%
Hydrogen	11·87%
Sulphur	0·51%
Nitrogen	0·11%
Oxygen (by diff.)	0·26%
	100·00

The crude oil is pumped from the fields to the refinery at Lutong where it is worked up in Trumble plants, two of which are at present in operation. The crude oil is heated by condensing vapours and by issuing residue before entering the tubular still. Leaving the still it enters the evaporator at the top, passing down over the umbrella shaped baffles, the vapours becoming disengaged and leaving by the vapour main, whence it passes through six dephlegmators in series. Water cooling coils on top of each dephlegmator enable the amount of reflux oil to be controlled. Seven fractions are thus obtained, six dephlegmator bottoms and one vapour from the last dephlegmator. The residue is drawn off from the evaporator, and after passing through the heat-exchangers passes on to the rundown tanks. The condensate from the first dephlegmator is a gas oil distillate. That from dephlegmator two passes into the first separator, this being practically a steam still aided by heat from a residue coil. The distillate from this separator goes into kerosene, the residue into gas oil. Similarly the condensates ex dephlegmators 3 and 4 are redistilled into separator No. 2, yielding heavy benzine and kerosene as distillate and residue. The condensate from dephlegmator 5 is similarly treated, that from dephlegmator 6 in this particular case running to benzine. The method of operation may naturally be varied according to requirements. The condensates from the dephlegmators gave the following distillation analyses :—

	D1.	D2.	D3.	D4.	D5.	D6.	Vapour ex D6.
Sp. gr. at 15° C. ..	0·914	0·884	0·868	0·856	0·839	0·815	0·779
Flash-point, ° C. ..	71	56	46	39	26	14	—
Initial boiling-point, ° C.	180	156	143	142	140	115	80
Percentage to 100° C.	—	—	—	—	—	—	1
do. 125° C.	—	—	—	—	—	—	47
do. 150° C.	—	—	—	—	—	22	83
do. 175° C.	—	—	4	6	20	55	96
do. 200° C.	—	9	18	26	51	81	—
do. 225° C.	2	22	42	56	82	95	—
do. 250° C.	12	50	72	83	95	—	—
do. 275° C.	40	82	93	97	—	—	—
do. 300° C.	77	95	—	—	—	—	—
Final boiling-point, °C.	—	317	290	280	260	242	180

Dephlegmator bottom D5 (for example) on passing through the separators was split up into a distillate and residue of the following characters :—

	Distillate.	Residue.
Specific gravity at 15° C.	0·807	0·852
Flash-point, ° C.	—	47
Initial boiling-point, ° C.	104	165
Percentage to 125° C.	2	—
do. 150° C.	33	—
do. 175° C.	74	—
do. 200° C.	92	39
do. 250° C.	—	96
Final boiling-point	220	268

The Trumble plant thus is able to complete the distillation of the crude in one operation, the necessity for separate redistillation steam stills being thus obviated.

The benzine as produced at the refinery needs no chemical treatment. The kerosene is subjected to the usual treatment with acid, soda and finally decolourising powder, only 1·6 per cent. of acid being required. The products are loaded, by means of submarine pipe-lines, into tankers, which are anchored two miles off the shore.

In conclusion, I wish to thank the staff of the Shell-Mex Laboratory who have assisted me in getting out many of the data on which these notes are based.

The Crude Oil of Maidan-i-Naftun.

By A. E. Dunstan, D.Sc., F.I.C., F.C.S.
(Member.)

In 1901 the late Mr. W. K. d'Arcy, prompted by rumours of oil in Persia, started a systematic investigation of the country, and in 1903-1904 drilled two wells at Kasr-i-Shirin, one to a depth of 800 ft., and the other to 2100 ft. Drilling was conducted in various districts but without any great success. After about $1,000,000 had been spent in this way, and there were serious thoughts of abandoning the whole project, oil seepages and springs in the neighbourhood of Schuster were heard of and these were examined. The first borehole, at a depth of 1100 ft., pierced the oil sands, and the oil spouted to a height of 70 ft., carrying away the derrick.

In 1909 the Anglo-Persian Oil Co., Ltd., was formed to work the concession obtained by Mr. d'Arcy.

The company's production at present is obtained from the Maidan-i-Naftun area, which is about 140 miles N.N.E. of Mohammerah. From here the oil is pumped through pipe-lines to the refinery on Abadan Island, at the head of the Persian Gulf, a distance of about 145 miles.

The following production figures indicate the rate of progress during the past twelve years :—

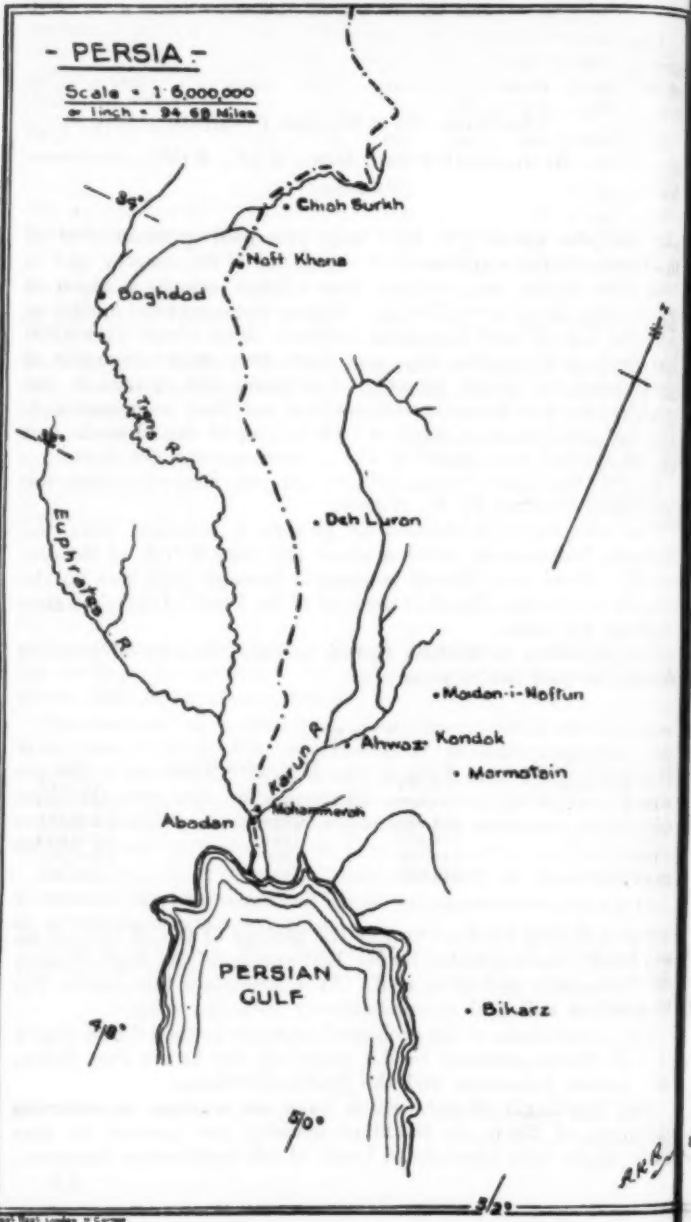
Table 1.

Year ended March.	Tons.	Year ended March.	Tons.
1912 (7 months) ..	43,084	1918	897,402
1913	80,800	1919	1,081,919
1914	273,635	1920	1,354,631
1915	375,977	1921	1,767,070
1916	449,394	1922	2,310,098
1917	644,074	1923	2,913,908

The following brief account of the geology of the oil formations was kindly communicated by Mr. Richardson, of the Anglo-Persian Oil Company's geological staff. At a later date this session Mr. Richardson will deal comprehensively with the subject.

The components of the geological sequence in the oil-field region of S.E. Persia pertinent to this paper are the Lower Fars Series, the Asmari Limestone and the Spatangid Shales.

The Spatangid Shales, which have an average approximate thickness of 250 ft. in Bakhtiari country, are greenish to blue fissile shales with intercalated bands of soft argillaceous limestone.


- PERSIA -
Scale • 1:6,000,000
or 1 inch • 94.69 Miles
Chiah Surkh
Naft Khana
Baghdad
Tigris R.
Euphrates R.
Deh Luran
Maidan-i-Naftun
Ahwaz
Kondok
Marmatein
Karun R.
Mohammerah
Abadan
PERSIAN GULF
Bikarz
30°
50°

The Asmari limestone is a massive to thickly-bedded limestone group, 1800–2200 ft. thick in the oilfield region; the exposures of this group, nearest to the oilfield, lie some 20 miles away to the S.E. at Asmari Mountain.

The Asmari limestone, so called from its exposures in the type area at Asmari Mountain, is the productive oil rock of the Maidan-i-Naftun oilfield.

The Lower Fars Series, consisting mainly of bedded gypsum, and red and blue shale, with salt, anhydrite and occasional detrital limestones, is the cap rock.

It had been previously considered that the reservoir rocks were detrital limestone of the Lower Fars gypseous group, similar in character to the occasional Lower Fars limestones which are intercalated with bedded gypsum, and in which the bulk of the surface oil seepages occur on the Field. It has now been proved conclusively by Mr. Richardson, upon petrographical palæontological and stratigraphical evidence, that the oil-bearing limestone is identical with the limestone of Asmari Mountain.

Samples of the oil-bearing rock submitted by him for analysis show it to be a highly dolomitic limestone.

The Natural Gas.

Large quantities of gas accompany the crude oil taken from the producing wells at Maidan-i-Naftun. There is little question but that at present, at any rate, the bulk of this gas comes to the surface dissolved in the oil or in the form of an emulsion, and is only separated from it on reduction of the pressure. The pressure on the well-head amounts to as much as 400 lb. per square inch. The pressure of oil and gas in the 10 in. mains leading to the gas separators is 55-60 lb. to the square inch. It is apparent, therefore, that during the reduction of pressure between the well-head and the separators and then at the separators, large volumes of soluble gases are likely to be disengaged.

The normal difficulties attendant on handling such volumes of gas are intensified by the presence of considerable quantities of sulphuretted hydrogen which render the gas very poisonous. Efficient separation and precautions against leakage are therefore of great importance.

Nature of the Gas.

The low pressure gas from the separators gives the following approximate analysis:—

TABLE 2.

Sulphuretted hydrogen	10% by volume.
Carbon dioxide	1%
Carbon monoxide	Trace.
Hydrogen	Nil
Argon, helium, etc.	Trace.
Olefines	Trace.
Paraffins	89%

Gas from the casing-head of Well B. 19 gives the following figures :—

TABLE 3.

Pressure	400 lb./sq. in.
Hydrogen sulphide	0·90% by volume.
Higher olefines	0·40% "
Carbon dioxide	0·35% "
Oxygen	0·25% "
Ethylene	0·35% "
Carbon monoxide	0·12% "
Hydrogen	Nil
C_nH_{2n+2}	96·36% "
Nitrogen (by difference)	1·27% "

Assuming that only ethane and methane are present in the paraffin content, the proportions are :—

Ethane	16·16% by volume.
Methane	80·20% "

The most striking figure is the high sulphur content of the low-pressure gas, which is almost unparalleled in naturally occurring gases, and renders the industrial application of the Persian gas a matter of some difficulty. It will be noted that the high pressure gas has yielded the bulk of its hydrogen sulphide to the accompanying oil.

The total absence of helium, and the presence of only traces of argon, is a matter of interest. The examination for rare gases was kindly conducted by Professor J. Norman Collie, F.R.S.

From its vapour density and calorific value the low pressure gas is to be classed as "wet," *i.e.*, it contains appreciable quantities of easily liquefiable hydrocarbons. After passing high-pressure well-head gas, which is already almost free from liquefiable constituents, through a freezing mixture of acetone and solid carbon dioxide, the original vapour density of 11·8 was reduced to 10·5. It appears, therefore, that the remaining gaseous hydrocarbons are preponderatingly methane.

DESULPHURISATION.

The gas employed at the Fields, and at the main pumping station at Tembi for power purposes, is desulphurised by treatment with milk of lime, but a continuous process based on the precipitation of

sulphur from hydrogen sulphide by the action of sulphur dioxide solution has given good results, and is under consideration for general adoption.

Utilisation of the Gas.

The complete exploitation of the Fields gas is imminent. It is intended to utilise the sulphur content, strip the gasoline as far as is practicable, and use the residual gas for power or in other ways.

Experiments have been carried out on the thermal decomposition of the gas. It is well known, of course, that the burning of natural gas against a metallic surface under conditions of incomplete combustion yields carbon black, a material for which there is a fair demand, but the process is scientifically uneconomical and therefore further work has been carried out on the complete pyrolysis of the gas.

The Crude Oil.

Persian crude oil is a mobile liquid, brown in colour, with a green fluorescence. Its mean specific gravity is 0·837. It flows from the wells accompanied by scarcely a trace of water.

It is an oleosol in which small amounts of asphaltic compounds and amorphous waxes are dispersed in a hydrocarbon continuous phase. This constitution is clearly shown by ultramicroscopic observation ; the asphalts are readily floculated by a trace of sulphuric acid, while the soft waxes are slowly deposited when the oil is allowed to stand undisturbed. A deposit of this nature was found to contain

Table 4.

Mineral matter	0·1%	Soft amorphous hydrocarbons	59·6%
Asphalts	17·9%		

The following analytical figures have been obtained from the crude oil :—

Table 5.

Carbon	85·4%	Oxygen and nitrogen (By difference.) ..	0·75%
Hydrogen	12·8%		
Sulphur	1·06%	Ash, less than	0·01%
Chlorine	0·01%	Hard asphalt	1·17%
		Wax (sweated & finished)	2·2%

The coke contains 0·48 per cent. of nitrogen, and the ash 2·8 per cent.

of vanadium, 1·7 per cent. of nickel, and 2·8 per cent. of manganese. The oil is chemically a "mixed base" crude, predominantly paraffinoid. Like most oils of Asiatic origin, it possesses a notable proportion of aromatic hydrocarbons. The benzine fraction, for example, contains 10 per cent. of benzene, toluene and xylene.

At 120° C. certain components of the crude oil decompose and liberate water, sulphur dioxide and hydrogen sulphide, which interact to form colloidal sulphur; consequently, in all the distillate tanks large quantities of elemental sulphur are found, particularly dependent from the roofs.

If, however, the oil is distilled in ample steam, and at the lowest possible temperature, the sulphur content of the distillates is considerably lessened, so that it is obvious that much of the thio-derivatives normally present in the benzine and kerosene are derived from the thermal decomposition of sulphur-containing compounds of high molecular weight.

Further evidence on this interesting point was obtained by debitumenising the crude oil by means of strong sulphuric acid. Quite a small percentage of acid will flocculate the asphalts, and on standing the bitumenised oil appears clear and bright, possessing a beautiful green fluorescence, not dissimilar from that of Hardstoft crude. On distilling this asphalt-free oil the following products were obtained:—

TABLE 6.

Fraction.	Sp. gr.	Sulphur.	Undebitumined.
Benzine	0·730 ..	0·01% ..	·08%
Kerosene	0·788 ..	0·08% ..	·15%
Gas oil and H.O. and P. ..	0·851 ..	0·59% ..	1·5%
Residue	— ..	1·70% ..	—

The bitumenised crude contained 0·74% sulphur.

A standard Engler distillation of the crude oil gives the following figures:—

TABLE 7.

Initial boiling point	35° C.		
Percentage to 150° C.	26%	sp. gr.	0·720
„ 150°–300° C.	32·5%	„	0·818
Residue	41%		

On distillation into 5 per cent. fractions, distillates possessing the following constants are obtained:—

TABLE 8.

5% Fractions of Crude. Sp. gr. 0·840.	Fractions. 1.	2.	3.	4.	5.	Fractions. 6.	7.	8.	9.
Distillations—									
I.B.P.	29°C.	41°C.	66°C.	88°C.	120°C.	135°C.	155°C.	180°C.	200°C.
10%	46·5	65	91	114	140	155	174·5	201	227·5
20%	51	70	95	118	143·5	158·5	177·5	204	233
30%	55·5	74	98	121	146	161	180·5	206	236
40%	59·5	78	101	123	148	164	184	209	238
50%	64	82	104·5	126	151	167	187	211·5	242
60%	70	87	108	130	154·5	171	190	216	245
70%	77	91·5	112	134	159	176	195·5	219·5	350
80%	85	98	118	139	165	182	201·5	226	257·5
90%	101·5	108	127	148	174·5	192·5	212	236·5	273
95%	—	—	—	157	187	203	222·5	247	298
F.B.P.	124	131	152	175	209	222	244	272	Above 300°C.
Sp. gr. at 60° F.	—	—	0·734	0·757	0·774	0·785	0·974	0·808	0·825
Sulphur %	—	—	0·10	0·11	0·09	0·08	0·11	0·16	0·31
Cal. value in calories	—	—	—	—	11,138	11,128	10,794	10,979	10,963
Flash-point	—	—	—	—	76°F. (Abel)	99° (Abel)	123° (Abel)	159° (Abel)	198° (Pensky)
Viscosity—									
Colour (Saybolt)	—	—	Better than +25	+25	+21	+24	+20	+8	—11
Refractive index at 20° C.	—	—	1·40860	1·42504	1·43170	1·43720	1·44243	1·44916	1·45836
Aromatics %	—	—	10·6	14·7	—	—	—	—	—
	Fraction 1—5 over 12 pear column.					Fraction 6—10 over 12 pear column using steam.			

TABLE 8 (*continued*.)

5% Fractions (contd.).	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.
				Fractions.						
Distillations—				Above	Above	Above	Above	Above	Above	Above
I.B.P.	205° C.	157° C.	248° C.	300° C.	300° C.	300° C.	300° C.	300° C.	300° C.	300° C.
10%	242	239	290	—	—	—	—	—	—	—
20%	248	253·5	296·5	—	—	—	—	—	—	—
30%	252	264	—	—	—	—	—	—	—	—
40%	258	272	—	—	—	—	—	—	—	—
50%	264	280	—	—	—	Semi-solid	Solid	Solid	Solid	Solid
60%	271·5	287·5	—	—	—	—	—	—	—	—
70%	280	298	—	—	—	—	—	—	—	—
80%	292	—	—	—	—	—	—	—	—	—
90%	—	—	—	—	—	—	—	—	—	—
F.B.P.	Above 300°	—	—	—	—	—	—	—	—	—
Sp. gr. at 60° F. ..	0·838	—	0·859	0·871	0·890	0·898	0·902	0·910	0·922	0·942
Sulphur %	0·43	—	1·02	1·27	1·35	1·42	1·48	1·71	1·89	2·09
Cal. value in calories	10,862	—	10,788	10,778	10,609	10,551	10,539	10,520	10,530	10,420
Flash-point	210° (Pensky)	—	266° (Pensky)	296° (Pensky)	306° (Pensky)	326° (Pensky)	356° (Pensky)	362° (Pensky)	—	388° (Pensky)
Viscosity in secs. ..	—	—	—	70·6 at 70°F.	104 at 70°F.	290 at 70°F. 86·1 at 100°F.	164·8 at 100°F.	495·6 at 100°F.	1398·8 at 100°F.	726·5 at 120° F.
Colour (Saybolt) ..				Too deep for instrument.						
Refractive index at 20°C.	1·46582	—	1·47801	1·48452	1·49095			Too dark.		
Aromatics % ..	—	—	—	—	—	—	—	—	—	—

From 50% Residue over plain still head.

5% Fractions (contd.). Fraction 20.

Residue.	A soft pitch.	
	Penetration at 10° C. for 50 gms.	0·082 cm.
	Melting point	56° C.
	Specific gravity at 15° C.	1·1
	Sulphur value	2·83%
	Calorific value	10,079 cals.
Analysis.	Bitumen (soluble in benzol)	99·4%
	Ash content	0·48%
	Organic matter insoluble in benzol (by difference)	0·12%
		100·00

Table 9.

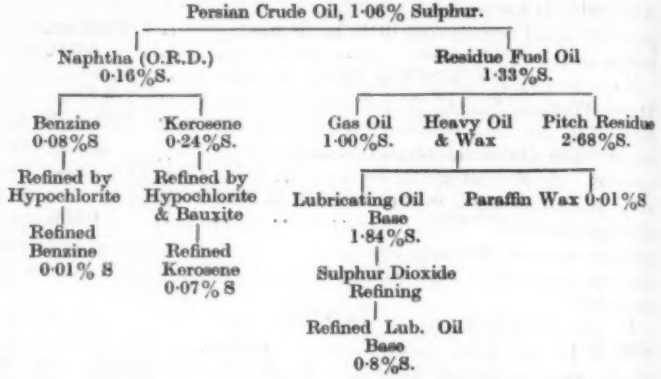
Engler Distn.	Fractions.													
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
I.B.P. ..	29	41	66	88	120	135	155	180	200	205	157	248		
10% ..	46·5	65	91	114	140	155	174·5	201	227·5	242	239	290	Above 300° C.	
20% ..	51	70	95	118	143·5	158·5	177·5	204	233	248	253·5	296·5		
30% ..	55·5	74	98	121	146	161	180·5	206	236	252	264			
40% ..	59·5	78	101	123	148	164	184·0	209	238	258	272			
50% ..	64	82	104·5	126	151	167·2	187	211·5	242	264	280			
60% ..	70	87	108	130	154·5	171	190·6	216	245	271·5	287·5			
70% ..	77	91·5	112	134	159	175·8	195·5	219·5	250	280	296			
80% ..	85	98	118	139	165	182	201·5	226	257·5	292				
90% ..	101·5	108	127	148	174·5	192·5	212	236·5	273					
95% ..				157	187	202·8	222·5	247	298					
F.B.P. ..	124	131	152	175	209	222	244	272	Above 300°					

Table 10.

Fractions.	S.G. at 60° F.	S.G.	Cal. value (cals.)	F. pt.	Vis. secs.	(Saybolt). Colour.	Ref. I. at 20° C.	Aromatic %	Crude S.G. ·840.
1 ..	0·663	0·018				Better than +25	1·37574	4·1	12 pear column.
2 ..	0·702	0·03					1·39202	6·1	
3 ..	0·734	0·10					1·4086	10·6	
4 ..	0·757	0·11				+25	1·42504	14·7	
5 ..	0·774	0·09	11,133	76° FA		+21	1·4317		12 pear w. steam.
6 ..	0·785	0·105	11,128	99A		+24	1·4372		
7 ..	0·794	0·11	10,974	123A		+20	1·44243		
8 ..	0·808	0·16	10,979	159A		+ 8	1·44916		
9 ..	0·825	0·31	10,963	198P		—11	1·45836		
10 ..	0·838	0·43	10,862	210P		Too deep	1·46582		
11 ..	0·842	0·73	10,858	186PM		,,	1·46681		From 50% residue over still-head. Metal condenser put on. Dist. semi-solid Solid.
12 ..	0·859	1·02	10,788	266PM		,,	1·47801		
13 ..	0·871	1·27	10,778	296PM	70·6 at 70° F.	,,	1·48452		
14 ..	0·890	1·35	10,609	306PM	104 ,,	,,	1·49095		
15 ..	0·898	1·42	10,551	326PM	220 at 70° 86·1—100°	,,	Too dark.		
16 ..	0·902	1·48	10,529	356PM	164·8—100°	,,			
17 ..	0·910	1·71	10,520	362PM	495·6 ,,	,,			
18 ..	0·922	1·89	10,530	344PM	1398·8 ,,	,,			
19 ..	0·942	2·09	10,420	388PM	726·5 at 120°	,,			

The *locale* of the sulphur in the various commercial fractions is shown in the following table :—

TABLE 11.



Technical Fractions of Maidan-i-Naftun Crude Oil.

In the primary distillation of the crude oil in continuous stills, 36 per cent. is taken off. This once-run distillate (O.R.D.) contains all the gasoline and some of the kerosene, while the 64 per cent. residue is of the appropriate flash point and viscosity for use as fuel or diesel oil.

A typical analysis of Once-Run Distillate gives the following figures :—

TABLE 12.

Sp. Gr. O.R.D.; 0.752 at 60° F.

Distillation Test.

I.B.P. 42° C.	..	..	
Vol. to 75° C.	..	..	4%
100° C.	..	..	17%
125° C.	..	..	41%
150° C.	..	..	63%
175° C.	..	..	80%
200° C.	..	..	89%
225° C.	..	..	95%
F.B.P. 248° C.			

Total Distillate	..	..	97·5%
Residue	..	..	1·3%
Loss	..	..	1·2%
Sulphur	..	..	0·13%

The Once-Run Distillate may be refined before cutting into gasoline and kerosene, or may be redistilled before treatment. The technical removal of the sulphur compounds has presented some difficulty, but, is conveniently accomplished by means of the hypochlorite process of refining.

Free hypochlorous acid or chlorine water may be employed in this oxidation, but of course, this treatment inevitably brings about

some chlorination, more particularly of the heavier components of the oil. If the product, after treatment in this way, is distilled, a perfectly good benzine distillate is obtained, whilst the chlorinated bodies in the residue are easily removed by adsorption on bauxite.

Many inventors have in the past suggested the use of free chlorine. Thus, Watson Smith (E.E.P. 2025/1880) passed chlorine into petroleum oils and distilled off a spirit of "faint and agreeable odour," but not characterised by any analyses showing its chlorine content. S. E. and E. E. Johnson (E.E.P. 4255/1875) prescribed very similar treatment and completed the refining by filtration through charcoal. It is, of course, obvious that chlorinated hydrocarbons are not desirable constituents of either petrol or kerosene and the removal of such compounds, if they have been formed, is essential.

In the hypochlorite process* the distillate is first washed with a 10 per cent. solution of caustic soda. The preliminary alkali wash removes hydrogen sulphide and sulphur dioxide, and organic sulphur compounds of an acidic nature; the greater part of the latter are only feebly combined with the soda and can be removed by boiling, thus rendering the soda available for further use. Efforts are being made to isolate definite sulphur compounds from the spent soda, and this work has already resulted in the separation of a body giving a mercury compound and a crystalline silver derivative. The compounds removed by the soda wash have a most objectionable odour, but the treatment effects only a partial removal, and the naphtha still possesses an unpleasant odour, although upward of 20 per cent. of its sulphur content has been eliminated if the naphtha is fresh; a less amount is removed from a stale distillate. The thioderivatives left in the oil after complete extraction with soda yield well defined mercury compounds. The examination and characterisation of these bodies are being actually pursued at the moment.

The oil is now treated with a solution of sodium or calcium hypochlorite (0·2–0·3N). It is important that this solution should contain free alkali equivalent to about 0·5 gms. of caustic soda per litre. If free alkali is not present the solution is too unstable, and slight chlorination of the hydrocarbons may result, as well as oxidation of the sulphur compounds, whilst the presence of more than 1 gm. of caustic soda per litre renders the hypochlorite almost inactive. This treatment, which takes from half-an-hour to an hour, reduces the sulphur content by approximately another 20 per cent., and completely utilises the available oxygen of the hypochlorite. A second similar treatment is now given, but a longer time is necessary for the hypochlorite to become exhausted;

* English Patents 139,223/18; 184,281/21; 204,078/22.

when the concentration falls to about 0·03 N, the operation is complete. The duration of the second wash may be curtailed by the use of a "destabiliser," *i.e.*, any substance which will reduce the concentration of hydroxyl ions. Appropriate acids, or salts with insoluble hydroxides, will activate the hypochlorite solution and accelerate the completion of the oxidation. The most effective "destabiliser" is carbon-dioxide, since it is readily available in the form of flue gases, and it neither liberates chlorine as stronger acids would do, nor does it cause the formation of precipitates which would tend to cause emulsification.

Sodium hypochlorite is a simple substance to manufacture. It may be made by the electrolysis of brine, in which case the current is so adjusted as to produce the appropriate quantity of free alkali at the same time. Solutions of a strength of 0·2–0·3 N may easily be obtained in this way.

Another method is to allow a 10 per cent. solution of caustic soda to absorb chlorine until the required strength is obtained. By this means 2 N solutions can be made containing free alkali in such proportion that, on dilution to the working strength of 0·3 N, there remains from 0·5 to 1·0 gms. per litre of free caustic soda. The absorption of chlorine is very readily controlled. Calcium hypochlorite can be made by the extraction of bleaching power or, better, by passing chlorine into well-agitated milk of lime.

After treatment with hypochlorite, the naphtha has entirely lost its unpleasant smell, but it still contains oxidised sulphur compounds; these may be to a large degree removed by washing with a 10 per cent. solution of caustic soda. The chemistry of the hypochlorite process is extremely simple, for the sulphur compounds are merely oxidised to sulphones, sulphoxides and sulphonic acids, and these oxidation products are readily soluble in alkali, or can be separated by distillation.

TABLE 13.

	Exp. 1.	Exp. 2.	Exp. 3.
Initial soda wash, % sulphur removed ..	13·7	4·8	19
1st Hypochlorite wash, % sulphur removed.	22·4	27·7	24
2nd Hypochlorite wash, % sulphur removed	19·0	21·7	14
Final soda wash, % sulphur removed ..	14·6	27·8	9
Redistillation, % sulphur removed	23·3	7·2	25
Total % sulphur removed	93·0	89·2	91

The Once-Run Distillate is now ready to be distilled into gasoline and kerosene.

During the distillation of the hypochlorite-treated Once-Run Distillate the small quantity of chlorinated products formed by the treatment are decomposed, with formation of hydrochloric acid. Provision for this is made by putting a small quantity of caustic soda into the still.

Gasoline.

The gasoline which is distilled from the hypochlorite-treated Once-Run Distillate requires no further refining. It amounts to rather more than 20 per cent. on the crude oil, and has approximately the following chemical composition :—

Table 14.

	%
Pentanes	7
Hexanes and methyl-cyclopentane	27
Heptanes, cyclohexane, dimethylcyclopentane and methyl cyclohexane	36
Octanes—dimethylcyclohexane	13
Benzene	2
Toluene	5
Xylenes	3

The following are typical analyses of graded spirits: Aviation Spirit, No. 1 Spirit, and No. 3 Spirit :—

Table 15.

	Aviation Spirit.	No. 1 Spirit.	No. 3 Spirit.
Sp. gravity at 60° F.	0·711	0·725	0·742
I.B.P.	36° C.	40° C.	39° C.
Vol. to 50° C.	Few drops	Few drops	Few drops
75° C.	17%	12%	9%
100° C.	65%	43·5%	31%
125° C.	89·5%	74%	63%
150° C.	—	93%	85%
175° C.	—	97%	95%
F.B.P.	149° C.	177° C.	190° C.
Total distillate	98%	97·5%	97·5%
Residue	1·4%	1·4%	1·4%
Loss	·6%	1·1%	1·1%
Sulphur, less than	0·01%	0·01%	0·02%

A careful fractional distillation of the Aviation Spirit through a 54 in. Raschig type column gave the following results :—

Table 16.

Distilling Range. ° C.	Yield. %	Sp. Gravity at 60° F.	
Up to 40	4·6	0·638	*n* Pentane B.P. 35° C.
40 to 50	2·1	0·645	
50 to 60	2·5	0·656	
60 to 70	21·1	0·683	*n* Hexane B.P. 66° C.
70 to 80	5·3	0·713	
80 to 90	8·1	0·720	
90 to 100	21·1	0·720	*n* Heptane B.P. 98° C.
100 to 110	11·8	0·744	Methyl cyclo-hexane B.P. 104° C.
110 to 120	6·9	0·737	
120 to 130	7·4	0·740	*n* Octane B.P. 126° C.
130 to 140	2·5	0·770	
Over 140	5·0		

Grouping together the appropriate fractions the composition is approximately as follows:—

TABLE 17.

Pentane		7%		
Hexane	+ Benzene	29%	of which 1·5%	is benzene.
Heptane	+ Toluene	41%	„ „ 3·5%	„ toluene
Octane	+ Xylenes	16%	„ „ 3·0%	„ xylenes.

The straight Aviation Spirit contains from 8–10 per cent. of naturally occurring aromatic hydrocarbons. The No. 1 Spirit is richer in xylene and contains about 10 per cent. of aromatic hydrocarbons. The specific gravities and critical solution temperatures in aniline of these fractions after removal of the aromatic hydrocarbons show that though the spirit is mainly paraffinoid, a certain proportion of naphthenic hydrocarbons are also present. All three spirits are perfectly colourless and very sweet-smelling. Owing to the complete absence of olefinic and other unsaturated bodies, they do not deposit gum, however long they are kept. They are inert to "Doctor" solution (sodium plumbite) and to copper. The refining is drastic, but singularly free from loss, owing to the elimination of acid from the treatment.

The advantages of the hypochlorite process as compared with the use of sulphuric acid may be summarised as follows:—

(1) There is less loss on refining, for no aromatic hydrocarbons are lost in the form of sulphonic acids.

(2) No acid sludge is formed, and no acid recovery plant required.

(3) The treatment can be carried out in ordinary steel vessels, since corrosion of washers, piping, etc., is much less than is the case when acid is employed. Lead-lined apparatus is not required.

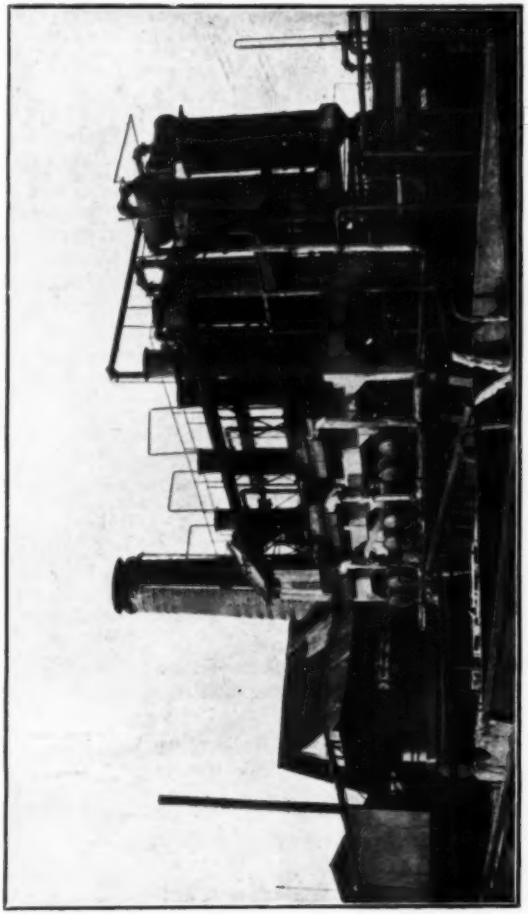
(4) The sum total of operations is easier to carry out than the acid refining process with the acid recovery, etc. incident to the latter.

(5) The process is applicable to the light distillates from all types of crude petroleum which contain sulphur.

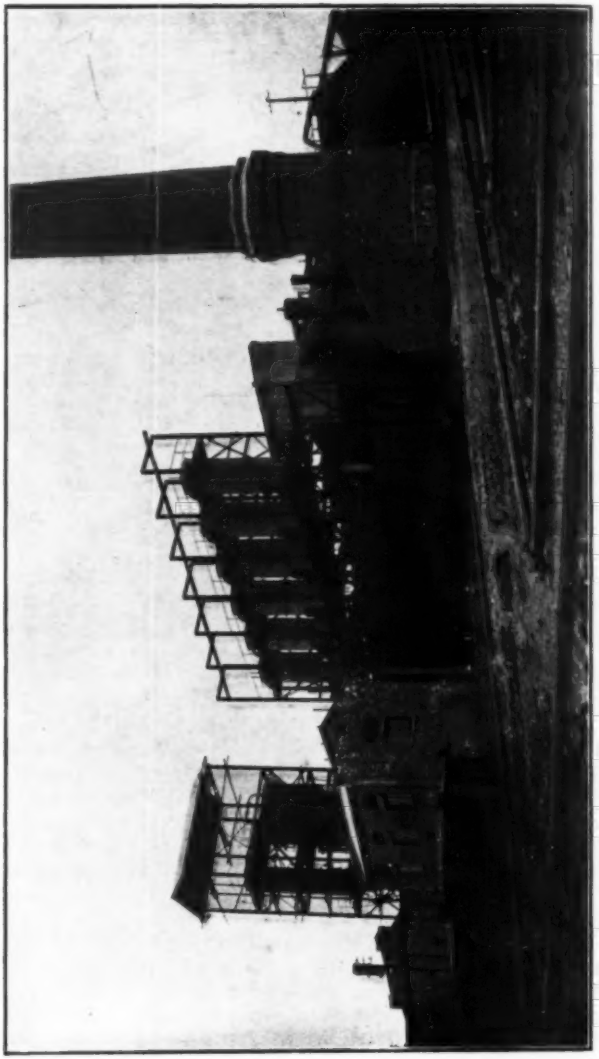
(6) The caustic soda used incidentally in the process is readily recoverable.

WHITE SPIRIT.

By making a suitable "cut" during the distillation of Once Run Distillate previously treated with the usual quantity of sodium hypochlorite, white spirit having a specific gravity and distillation range to satisfy the usual specifications can be obtained. By a further light bauxite treatment (half pound per gallon) a superfine



A DISTILLATION UNIT, TRUMBLE SYSTEM.



CRUDE OIL BENCH, LANDARCY REFINERY, SEBWAN.

product can be prepared. The white spirit described below is one made in considerable quantities and constitutes about 10 per cent. of the Once Run Distillate, or 4 per cent. of the crude.

A typical distillation test is given below:—

TABLE 18.

S.G.	=	·780 at 60° F.	60%		168
I.B.P.	..	135° C.	70%		171
10%	..	157	80%		176
20%	..	159	90%		188·5
30%	..	161	95%		189
40%	..	163	Dry at		195° C.
50%		165·5	Flash Pt.		99° F.

KEROSENE.

After removal of the petrol fraction from the light distillate which has been treated with hypochlorite the residue in the still has an average specific gravity of 0·800, a flash point of 120° F. and a pale yellow colour. At this stage of refining the sulphur content of the crude kerosene, which represents 15 per cent. of the crude oil, averages 0·15 per cent., and this must be materially reduced in order to produce a marketable product. The most efficient means of reducing the sulphur content and removing the colouring matter in one operation consists in a simple filtration through bauxite.

The bauxite is first activated by roasting in excess of air at 550° C. While still warm it is packed into filters and a predetermined volume of kerosene is allowed to percolate through a definite weight of the bauxite. The filtering medium is then steamed to remove adherent kerosene and adsorbed sulphur compounds, after which it is returned to the furnaces for regeneration. The usual treatment consists of about 3 lbs. of bauxite to the gallon of filtrate, by which means the sulphur content is reduced to rather less than 0·1 per cent., and a colour superior to water white is obtained. In this process the roasted bauxite, which is by no means completely anhydrous, acts as a surface adsorbent and the adsorption both of colour and of this derivative follows the Freundlich law. By refining in this manner a kerosene is produced which is stable in colour and odour. Like all other similar products—from whatever source the crude oil may be obtained—the colour and odour deteriorate on exposure to direct sunlight. This agency appears to be the main factor in bringing about reversion, which takes place even when a sample is sealed up in a glass vessel *in vacuo*, though the rate of deterioration is greater when air is admitted to the presence of sunlight. The nature of the gum deposited from reverted kerosene has been the subject of a considerable amount of investigation, which, however, has not yet proceeded far enough to

CRUDE OIL BENCH, LLANDARCY REFINERY, SKEWAN.

warrant definite assertions to be made regarding its chemical constitution and method of formation. It can, however, be stated that there are at least two constituents in the gum, one of which is apparently an organic acid free from sulphur, and seems to be the chief colouring compound. This fact is important, in view of the repeated statement that gum formation in petroleum distillates is largely due to the presence of sulphur compounds. Even with a sulphur content of 0·01 per cent. similar gums have been obtained. They are conceivably oxidation products of olefinic hydrocarbons.

A point of practical importance in the above method of refining is the elimination by means of bauxite filtration of those traces of soda or sodium salts, which, even in minute quantities, are the cause of filming on lamp glasses.

The finished kerosene has a very pleasant odour, resembling that usually associated with white spirit, and quite unlike the ordinary "paraffin" smell of American lamp oils. It has a specific gravity of about 0·790, and a closed flash point ranging from 95–120° F., according to market requirements.

A typical analysis is as follows:—

TABLE 19.

Sp. Gr. at 60° F., 0·788.

Distillation Test.

I.B.P.	121° C.	
Vol. to	150° C.	7%
	170° C.	44%
	200° C.	70%
	225° C.	86%
	250° C.	93·5%
	275° C.	97%
F.B.P.	279° C.	
Total distillate		98%
Residue		1·5%
Loss		0·5%
Colour		+23½ Saybolt
Flash Point		95° F. A.P
Smell		Good
Sulphur		0·7%

LONG-TIME BURNING OIL.

A special cut may be made in the kerosene from which Long-Time Burning Oil or Lighthouse Oil is prepared.

FUEL OIL.

Persian Fuel Oil (64 per cent. residue) has a specific gravity in the neighbourhood of 0·897. It has a sulphur content of about 1·33 per cent. and a flash point of over 175° F., thus conforming

with the Admiralty specification. Its water and adventitious matter content is of the order of 0·1 per cent., and its hard asphalt (insoluble in petroleum ether) averages 1·8 per cent.

Its low asphalt and sulphur content and high calorific value make this oil a very valuable fuel.

A typical analysis is as follows:—

TABLE 20.

Carbon	86·2%	Hard Asphalt	1·8%
Hydrogen	12·4%	Soft Asphalt	2·3%
Sulphur	1·3%	Solid Paraffins (Holde method)	6%
Nitrogen, Oxygen, etc.	0·1%	Gross calorific value	19,600 B.T.U.
Specific gravity	0·896	Coke (Conradson)	3·5%
Flash Point	179° F.		

Distillation Test.

I.B.P.	186° F.				
Vol. to	200° C.	0·5%	280° C.	17%
	220° C.	2·5%	300° C.	24%
	240° C.	6%	320° C.	30%
	260° C.	11%	340° C.	38·5%
			360° C.	45·4%

Viscosity Redwood No. 1.

At 60° F.	250 secs.	140° F.	55 secs.
80° F.	130 „	180° F.	41 „
100° F.	89 „		

The viscosity at 100° F. (Redwood 1) is 80-100 seconds, but at lower temperatures (below 40° F.) it is indefinite; the figure may range from 200 seconds to several times this value. The reason for this variable viscosity at low temperatures is that this fuel oil is a colloidal solution of certain amorphous hydrocarbons in oil,* and this solution consequently behaves in the manner characteristic of emulsoid sols—*i.e.*, its viscosity is dependent, not only on the concentration of the emulsoid, but also on age and previous thermal and mechanical history. This peculiar characteristic may be completely eradicated by subjecting the oil to a mild cracking treatment which destroys the hydrocarbons which form the disperse phase.

CRACKING.

Persian residues can be cracked successfully for the lowering of viscosity or the production of light spirit.

A mild form of cracking, whereby the oil is subjected for a limited time to temperatures of approximately 400° C. and pressures of about 200 lb. per square inch, has successfully overcome the "gelling" phenomenon characteristic of the heavier Persian residue.

* See discussion to Glazebrook, Pannell and Higgins, Journ. Inst. Petr. Techn., ii, pp. 73-75, Pt. 5, Dec., 1915.

This gelation occasionally causes some difficulty in the use of 50 per cent. or more concentrated residues as fuel oils in cold climates, owing to the considerable increase in the viscosity of the oil on standing. This hysteresis effect is fully described in Glazebrook Pannell and Higgins' paper and the discussion thereon. It would appear that in the fuel oil, the asphalt and the soft paraffins act as mutually protective colloids, but after standing for any length of time a change in the physical or chemical nature of the asphalt allows the soft paraffin to change from the sol to the gel form. By the mild cracking process mentioned above, the proportion of soft amorphous hydrocarbons is reduced to a point where the asphalt is sufficient to keep it in the liquid form, with the result that the residues so treated form satisfactory fuel oils of low viscosity. Only limited amounts of light spirit are formed during the treatment. In connection with this the interesting observation has been made that highly asphaltic oils mixed with heavy Persian residues, bring about such a protective effect that gelation is inhibited and the mixtures keep permanently liquid at low temperature.

In order to obtain gasoline, Persian residues have been cracked successfully by a liquid phase process. As far as the oils themselves are concerned, they behave normally, except that considerable quantities of sulphur are disengaged both in the elemental form and as sulphuretted hydrogen. This elimination of sulphur is all to the good, since the cracked gasoline and kerosene formed contain very little more sulphur than the corresponding straight run products.

The liquid-phase process has been operated successfully to produce from heavy residue upwards of 15 per cent. of gasoline, which may be refined with the greatest of ease by any of the known processes. The finished product is perfectly colourless, and after adequate refining does not gum. Its odour, though characteristic, is pleasant, and during observation periods of a year shows no sign of reversion.

Products Obtainable from Persian Fuel Oil.

That quantity of 64 per cent. residue from the continuous topping stills which is not destined for use as fuel oil is further reduced in the residue bench.

The first product obtained is kerosene, which may be employed to supplement the Once Run Distillate residue, and also as a source of long-time burning and lighthouse oils. This kerosene fraction constitutes 25 per cent. of the fuel oil, or 16 per cent. on the crude; its specific gravity is about 0·828, its flash point 120° F., and its sulphur content 0·5 per cent. The refining of this fraction presents no especial difficulty, and in fact it is quite amenable to a simple bauxite treatment.

Gas Oil.

The next 12 per cent. of the fuel oil is the gas oil fraction. Its specific gravity is 0·850 to 0·865, its flash point 170–200° F., and its sulphur content is of the order of 1 per cent. A typical analysis displays the following figures:—

Table 21.

Specific gravity	0·858	30%	290
Flow point	14° F.	40%	300
Flash point	170° F.	50%	310
Sulphur	1·13%	60%	318
		70%	324
10% distilling to	259° C.	80%	336
20%	278	90%	352

It may be used as a fuel for oil engines, and for carburetting water gas, and is also very suitable for cracking stock.

Using Persian gas oil of specific gravity 0·864, a liquid phase cracking process has been operated successfully in five-day cycles, to produce 30 per cent. of gasoline, 25 per cent. kerosene, 40 per cent. gas oil, and 5 per cent. residue and loss.

A vapour phase process developed to deal primarily with Persian gas oil has given peculiar results. In this method of treatment gas oil vapour is cracked within the pores of activated charcoal, the underlying idea being that when absorbed into the charcoal or other agent the vapours are under high adsorbed pressure. Cracking takes place and the light products are replaced by incoming heavier vapours.

The gasoline obtained by this method, without any refining whatever, possesses a smell almost identical with that of a straight run gasoline, and does not deposit gum on keeping. Moreover, the residue from its distillation up to 200° C. consists very largely of almost pure naphthalene, which solidifies in the distillation vessel. Whether the naphthalene is produced synthetically under the conditions of the treatment, or by dehydrogenation of hydronaphthalenes originally present in the gas oil is not yet clear.

Heavy Oil and Paraffin.

After the removal of the gas oil from 64 per cent. residue, the next 30 per cent. is H. O. and P. This amounts to 19 per cent. on the crude, has a specific gravity of 0·886, a flash point of 290° F., and contains sulphur to the extent of 1·3 per cent. It is cooled and pressed in two stages to remove the wax, the final pressing being carried out at 15° F. The filtrate "blue oil" now passes to the

sulphur dioxide oil refining plant, where it is given one extraction with liquid sulphur dioxide at about 20° F.

The oil and sulphur dioxide are thoroughly mixed by pump agitation, and allowed to settle. The heavier sulphur dioxide layer, and then the refined oil, are pumped to separate evaporators, from which the sulphur dioxide is recovered by distillation and heating under reduced pressure. The sulphur dioxide dissolves some of the aromatic and most of the unsaturated hydrocarbons, bodies rich in sulphur, and some substances which cause the oil to form asphaltic sludge on oxidation by air at elevated temperatures. The volume of the extract is 12–15 per cent.

The effect of the treatment may be seen from the typical data in the following table :—

TABLE 22.

	Blue Oil.	SO_2 refined Blue Oil.	SO_2 Extract.
Sp. gr. at 60° F.	0·896	0·878–0·880	0·98–0·99
Viscosity at 70° F.	130 secs.	120–125	200–300
Sulphur	1·5%	0·9%	3·8%
Iodine value by Wij's soln. 1½ hrs. at 15° C.	33·4	20·1	66·2
Comparative interfacial tension to water	2·3	1·25	4·5

Both the refined oil and the extract are given soda and water washes to remove dissolved sulphur dioxide.

The refined blue oil constitutes a lubricating oil base which, on distillation, yields about 50 per cent. of its volume of gas oil. The fraction between 50 per cent. and 90 per cent. gives light and medium spindle and engine oils, while a 90 per cent. to 100 per cent. residuum after filtration for colour yields a good quality oil suitable for water-cooled internal combustion engines. Lubricating oil suitable for air-cooled internal-combustion engines can be obtained by reducing to a 95–100 per cent. residue.

Owing to the fact that Persian crude oil is rather light in character, and also that at present a deep cut is not being made into the pitch, the yield of very heavy lubricants is small, but the oils which have been produced up to date are characterised by an exceedingly small oxidation test, the total amount of sludge formed being an unweighable trace, using a modification of Michie's well-known Transformer Oil Test. On the other hand, 50 c.c. of the sulphur dioxide extract under similar conditions will give as much as 2600 milligrams of sludge, thus showing that the oxidisable bodies are almost completely removed with the sulphur dioxide.

The extract is, at present, returned to fuel oil, but it can be further refined.

In the ultra microscope the lubricating oil fractions are clearly seen to be two-phase systems and characteristically fluorescent; whether all such distillates from any source are colloids or not, is open to question. Possibly these oils are isocolloids as described by Wo. Ostwald. The result of the examination of a large number of lubricating oils in this way would be of considerable interest in connexion with the attempts being made to elucidate the nature of oiliness.

Wax.

The scale obtained by cooling and pressing the Heavy Oil and Paraffin is re-pressed under hydraulic rams at ordinary temperatures and sweated in the usual way. The wax thus obtained is further purified by hypochlorite and soda washes, and is finally filtered through bauxite. When fully refined the wax has a specific gravity 0·914, a sulphur content of less than 0·01 per cent., a melting point 130-135° F., and a colour equal to 0·6 yellow in the 18 in. Lovibond Cell. The yield of high melting finished wax is 6·2 per cent. on the H. O. and P. or 1·2 per cent. on the crude oil.

Other Products.

The Heavy Oil and Paraffin may also serve as the source of superfine chemical products, such as Paraffinum Liquidum and Petroleum Jelly, both of which may readily be made to pass the recognised specifications.

Ash.

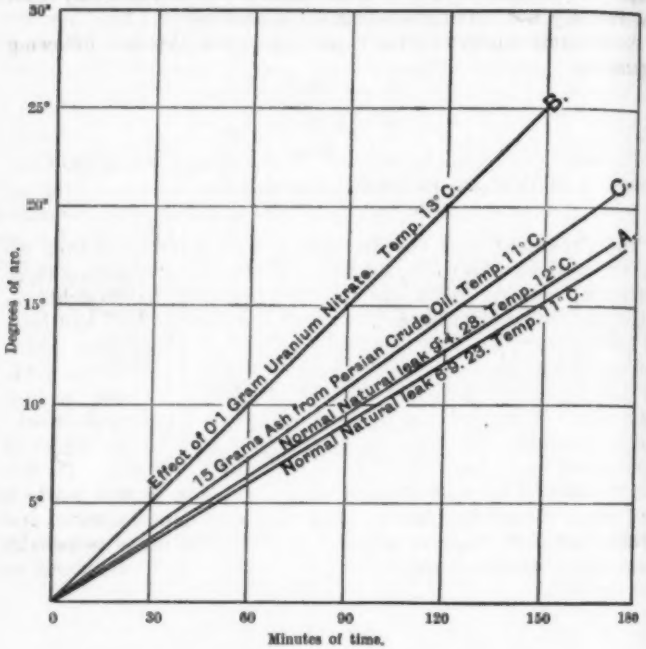
Persian Crude Oil contains less than 0·01 per cent. of ash, which has the following composition :—

Fe_2O_3 and Al_2O_3 ..	26·96%	MnO	4·39%
CaO	2·31%	SiO_2	2·29%
MgO	1·18%	P_2O_5	5·53%
V_2O_5	5·03%	SO_3	35·29%
NiO	2·70%	Moisture	—

The most striking feature is the large percentage of vanadium and nickel—two of the most active catalytic agents known in the metallic state. It is a moot point, however, in what way these elements are associated in petroleum; nothing is known to explain their presence therein. It should also be noted that the ash exhibits a small degree of radio activity, 15 grams of ash showing about two-thirds of the activity of 0·1 gram of Uranium Nitrate when tested by the usual method.

TESTING FOR RADIO ACTIVITY IN PERSIAN CRUDE OIL.

Curve A shows approximation of the natural leak of electroscope used under Normal conditions.
Curve B shows the effect of 1 gram uranium nitrate on the electroscope.
Curve C shows the effect of the 15 grams. of Persian crude ash in the electroscope.



The final residue of pitch can be used as insulation material, or as an asphaltic road-making material provided the distillation is carried on to the appropriate stage.

The exact cutting point can only be ascertained by large-scale tests and the construction of trial road surfaces, but a close indication is given by the following data :—

Residue (percentage on crude).		Melting Point.		Penetration at 25° C. with 100 gms. load (Dow)
5%	.. Over	212° F.	..	nil
5·6%	..	210° F.	..	1·3
6·0%	..	190° F.	..	7·0
7·0%	..	175° F.	..	10·0

The 5 per cent. residue is too brittle and hard, and the 7 per cent. is too soft and fusible. The most suitable residue is between 5·5 and 6; this asphalt is of high quality for road surfacing.

The ductility is excellent, so that a little air-blowing would be permissible if it were desired to raise the melting point somewhat for use in tropical climates. Air-blowing should, however, be employed only if it cannot be avoided, as it detracts seriously from the ductility and binding power of the asphalt.

An ultimate analysis of the 6 per cent. pitch gave the following figures :—

C = 86·2%
H = 8·8%
S = 3·4

The author's thanks to the staff of the Anglo-Persian Oil Co's. Research Station are gratefully acknowledged.

The President said the Institution was greatly indebted to the two authors who had taken so much trouble in preparing these interesting papers. This was the first occasion, he thought, on which the characteristics of these particular classes of oil had been so clearly detailed and described to them. One point which interested him specially, was the reference that Dr. Dunstan made to distillation and refining, and the elimination of acid in that treatment. They all knew the trouble there was with tank vessels, due to corrosion. If they could only do away with the traces of acid especially in spirit, it would be a great advantage. He felt almost inclined to suggest that no spirit should be carried in which any acid was used in refining. That was an important point, and would appeal to a great many shipowners. He was personally very interested in the paper, but he would leave the discussion to the chemists.

DISCUSSION.

Dr. W. R. Ormandy said that one was somewhat diffident in getting up to speak on papers such as those they had just heard, not because there was not enough material, but because there was so much, and one did not know where to begin. They would all substantiate the wish expressed by Dr. Dunstan, that they might have more papers of this type, particularly papers dealing with the physical and chemical characteristics of oils at various depths, correlated with the geological features at the same depths, because it was only by a study of those two taken in juxtaposition that they might ever hope to solve the great problem as to the origin of petroleum.

The points raised in the first paper were so numerous that one could only pick out those in which one was personally most interested. It was not the fact that an oil like petrol was fully described,

merely by giving a complete list of its usual physical and chemical properties. Petrol was required as a means for propulsion in the internal-combustion engine. Although it was perfectly true that the energy that could be derived from any sample of petrol was directly a function of its heat value, plus its latent heat of evaporation, that was only true when speaking of engines of one compression. Engines were being built of ever-growing compressions, and it was a fact that there were on the markets to-day spirits which certain types and classes of engines could not use; and there were other spirits which could be used. If a spirit could only be used at a compression so that there was a maximum thermal efficiency of 25 per cent., whereas another spirit could be used at such a compression as gave a maximum thermal efficiency of 35 per cent., then even though the heat values of those two fuels were alike, one fuel was 40 per cent. better than the other. In a paper to be read at the Institution of Automobile Engineers on Aviation Engines, the author would state that the greatest difficulty with which aviation engineers were faced was the question of the varying quality of the fuels which they had to fit their engines to use, and that whereas they could design engines capable of giving much higher powers, they had to design them so that they were suitable for the worst fuel which they might have to employ commercially. He believed the time was coming when those who supplied petrol would be asked to give some figure which was a measure of the compression which could be employed. It was very discouraging as a chemist to have to admit that neither chemically nor physically could they, from a statementof the physical and chemical properties of the fuel, state with any degree of certainty what compression a fuel would stand. They might have to specify that in some variable compression engine, which should be accepted as a standard, a fuel would stand a compression of 4 to 1, 4½ to 1, or 5 to 1, as the case might be. It did point to the fact that chemists and physicists required to do a great deal more in order that they might get to the bottom of whatever it was which enabled fuels to be used under those varying conditions. That point was brought to his mind by a statement in Mr. Kewley's paper, where he referred to the Miri benzine as showing 5 per cent. of aromatics, the balance being almost entirely naphthenes. He knew well that Mr. Kewley recognised the great difficulties there were in estimation of naphthenes. Paraffin would stand the lowest compression, naphthenes would stand the next higher compression, and aromatics a still higher compression. It was therefore important that they should be able to estimate, so far as was practicable, the relative percentage of these three ingredients in fuel. For that reason, investigation and work should be done on the methods for the determination of those various constituents. He, personally, was always in doubt

as to what was meant by naphthenes in statements occurring in any author's work, because usually it was assumed that paraffins and naphthenes were left after they had washed out the spirit with acid of a certain strength; but he thought undoubtedly acids of the strength employed in such washing took out some of the less hydrogenated naphthenes. The question was, what should they call naphthenes? They must specify something, and he thought the whole subject of the nomenclature of unsaturateds, naphthenes, and aromatics, and the means to be employed for testing, ought to be definitely described by somebody so that they might all work on the same footing, and when they spoke of naphthenes they would all mean the same thing.

Mr. Kewley had referred to the behaviour of Miri fuel oil with formaldehyde. That brought up another interesting point, which was the question as to what the unsaturated hydrocarbons were. Some people said they were estimated by bromine absorption, and others suggested they might be measured by formaldehyde reaction. He and his colleagues had carried out certain work recently, and had found a certain petrol which showed no bromine absorption at all, but it had been possible to obtain about 70 per cent. of this petrol in the form of a resin by the continued action of formaldehyde and acid. It was, therefore, obvious that neither the bromine nor the formaldehyde tests were measures of the same thing—they overlapped—but there was an area in which each of them had its own realm.

As regards sulphur, he thought it would be desirable if, in dealing with such things as motor spirits and kerosenes, some distinction were made between that sort of sulphur which was really of comparatively small importance in the fuel, and the sulphur which was present in the form of elementary crystalline or colloidal sulphur, causing corrosion on metallic parts.

It was quite impossible, as there were many other people who wished to speak, to refer at any length to the many points raised in the very complete paper of Dr. Dunstan, but he thought they might congratulate him on having worked out the chlorine or hypochlorite process, which was evidently one requiring very fine adjustment, because when one learned that when the free alkali was one gramme per litre there was little or no action, and then when there was less than half a gramme the action was so violent that trouble arose and chlorination took place, that showed clearly something which had been very difficult to work out on a commercial scale. He would like to say that the method if applied, as it had been applied, for refining benzene and coal tar derivatives, gave a spirit which was quite white, and it reduced the loss as claimed by Dr. Dunstan; but left a spirit which would not pass the ordinary acid washing test. If one shook up 100 c.c. with 10 c.c. of ordinary

strong sulphuric acid for a minute or two, one got a black mess in many cases. Yet he was quite sure that the spirit which had been so refined, and he was speaking of the coal tar derivatives, was just as good for use in a motor-car, though if it did not stand that test. That brought them to the point that the question of tests was one which had to receive fresh consideration in view of the new methods of refining. It was unfair to condemn a method of refining which gave a perfectly good product for the purposes for which it was required, because it would not stand a test, which test was only valuable when applied to the old methods of refining which were no longer solely in vogue. He had not had any opportunity of testing a large number of petrols, since the method of refining with hypochlorites was not yet widely used; but he submitted that that was a point which would have to receive consideration, and it was a point which the Standardisation Committee of the Institution ought to take in hand. With regard to the Trumble plant, he would point out that the method of fractional condensation, not the distillation operation, which was employed, was worked out in very great detail by Walther Feld, and used by him in his wonderful plant for dealing with products from the distillation of lignite in Austria, whereby he separated tars, heavy oils, light oils, spirits and ammonia, in a series of five vessels, giving products which, in many cases, were sufficiently pure on their immediate production to require no refining before being passed into commercial use.

Mr. J. McConnell Sanders said that they owed a very special vote of thanks to Dr. Dunstan for his very interesting paper, and more so because he had allowed them to have a little view, not very detailed perhaps, but affording them at least an insight into actual refining processes. Details such as these were very often slurred over in technical papers and thus comparisons between commercial products prepared by different refinery methods were not often easily made. It had struck him when listening to this paper, that Persian crude oil was very similar to some of the Mexican crudes and the details which Dr. Dunstan had put before them regarding the methods used in refining Persian crude were very valuable and allowed comparisons to be made as regards the ultimate effect of different refining methods on the products. The natural gas which accompanied Mexican crude oil was also extremely high in hydrogen sulphide—between 5 and 6 per cent. The ash from Mexican crude frequently contained vanadium, manganese, nickel, and phosphorus, hence it might be inferred that the products from Persian crude oil would exhibit some similarity to those from Mexican crude. He noticed that the Persian spirit was stated by Dr. Dunstan to contain from 8 to 10 per cent. of aromatics. He had a distinct impression, though he

had not been able to prove it conclusively, that spirits which had been treated by the hypo-chlorite method were prone to detonate or cause pinking in a high compression engine. It seemed remarkable that a spirit which contained so high a percentage of aromatics should be prone to detonate, and one was led to think that if minute traces of substances such as selenium compounds could remove this tendency, was it not equally possible that minute traces of chlorine compounds could cause such oils to detonate. Mexican petrols also had sometimes been found to detonate easily.

With regard to the refining of Persian kerosenes, the method of removing sodium compounds was mentioned as being necessary because oils which contained them cause filming of the lamp glass. He did not think, however, that filming of a lamp glass was necessarily always due to the presence of sodium compounds. It had been definitely traced, in his experience, to the formation of sulphuric acid in the case of highly sulphurous lamp oils. It had also been traced in another case to the presence of phosphorus. It might be mentioned that a very sensitive test for phosphorus consisted in heating the organic substance containing it on a polished glass rod and even minute quantities could be detected by the corrosion of the glass surface. It is worthy of remark that the ash of Persian oil contained phosphorus just as the Mexican did. Finally, in the elementary analysis of the crude oil he noticed that nitrogen and oxygen were estimated together by difference. Since Mexican oils especially those of the normal thio-asphaltic type are remarkable for the low percentage of nitrogen, he would like to ask Dr. Dunstan if he could give them any indication of the actual percentage of nitrogen alone in the crude oil, in order that they might correlate their information regarding the similarity between Persian and the Mexican types of thio-asphaltic mixed base crudes.

Mr. E. H. Cunningham-Craig said there were a great many things he would like to speak about in connection with these two papers, but he realised that the time was too short. For instance, he would like to supplement the early history of the work in Persia that Dr. Dunstan had given them, but perhaps the time had not yet come for that. He hoped some day that Mr. Reynolds would give them an account of it. It would surprise many people to know how very nearly there was no Anglo-Persian Oil Company at all. Mr. Reynolds and he were there at the start and he could assure everybody that the tale when it was told would be a very interesting one. He was also glad to hear Dr. Dunstan speak so openly about colloidal systems and disperse phases in connection with crude petroleum, a subject in which he had taken very great interest in the last five or six years.

To him perhaps the most interesting thing in these papers was the differences one found in oils at different depths and under different conditions. Those were matters that had been worked out pretty considerably in many parts of the world. In Persia the upper oils, that is to say the oils that were found in the detrital limestone above the Asmari limestone, were much heavier and much more sulphurous. They were so sulphurous in fact that in the cavernous limestone they found, long after the oil had been washed out of it, beautiful incrustations of crystalline sulphur. The amount of gas which came out from the seepages from the upper limestone, the detrital limestone, was so great that not long before he visited Persia two Persians who had gone to bathe in a little stream were found dead through being overcome by the sulphurous gas. The reason for the difference between that upper oil and the regular oil of 0·837 sp. gr. was simply a matter of inspissation, that is to say, weathering. There were several other things which affected oil underground. First, there were the conditions under which it was originally formed. It was known that the deeper one drilled in a regular oilfield, after a certain depth, lighter oils were nearly always found. At great depths, or when oils which had been formed under very high pressures were obtained, there were generally found to be paraffin oils, whereas the oils that were got at shallower depths, or that had been formed never at any very great depth, were naphthenic oils. There were several conditions which affected oil. There was inspissation, which might affect it to the depth of 500 or even 1000 ft. That depended on the strata in which it was found. When the strata contained thick clays and water, and were well sealed, so that dissipation of gases, which really affected the whole composition of the oil, was prevented, lighter oils were obtained. Oxidation also occurred to some extent in the weathering zone. The other point was the effects of filtration, because oils were not found where they were formed, but sometimes at great distances from the original source. He would take the cases of Persia and of Egypt. There they were dealing with an almost waterless series. The result was that the oil might have travelled a very great distance across strata without losing very much, but always being affected slightly by filtration. They had seen in Egypt that there was a heavy oil, apparently a mother oil, in the Nubian sandstone. By filtering that oil carefully they could produce a final result very much like the oil at Jemsah which was found in the Miocene far above. They had both the same origin no doubt, but the one had been very highly filtered during its migration. In Persia there was an oil which so far as they could make out—they were not quite certain yet where it came from although they had a good many ideas on the subject—had travelled a considerable distance

to get into the Asmari limestone. In that considerable distance he had no doubt that it had lost a great deal of its heavy asphaltic contents, but had not lost its paraffin. It was interesting to know that one of the theories as to where that oil was formed put the origin in the Cretaceous rocks just as the Nubian sandstone (Cretaceous) in Egypt. But they got no heavy oil in Persia like the heavy oil from Hurghada in Egypt. It was quite possible that there was heavy crude originally in Persia and that the oil they got in the Asmari limestone had through its lengthy migration been robbed of a great deal of its asphaltic content and probably at the same time of a great deal of its sulphur content. Inspissation gave them heavier oil near the surface; the sealing up prevented dissipation of light oil and gas, and filtration. Then came perhaps the most interesting point of all, and that was the original oil as it was formed. The original oil as it was formed was never seen. By the time it came to the surface it had disengaged so much gas that it was of a considerably different composition, but it was known that under different pressures different original crude oils formed.

Mr. J. E. Hackford said he must thank both Mr. Kewley and Dr. Dunstan for the intimate details they had given of the chemical analyses and characteristics of the products at their disposal. In a paper he had the honour of reading before the Institution* he raised the question of ash content and of gas analyses of the various fields. He was pleased to see that attention had been given to these matters and that the gas analyses and ash contents of the oils had been discussed at such length. The gas analysis of the oil given by Dr. Dunstan was in itself a proof of his statement as to the large percentages of paraffin in that oil while the nitrogen content was indicative of relatively small percentages of aromatic compound†. With regard to the ash content, these again were of very great interest. It had been found in some fields that vanadium had existed throughout a wide area of several hundred square miles and that at some isolated places in that district there was one spot where oil of a totally different character was found which did not contain the same elements. The question of phosphorus in the oils had always been of interest inasmuch as one was apt to correlate it with questions of animal, rather than vegetable organic origin. He would be very pleased if Dr. Dunstan in his reply would advise them as to the method he employed in detecting that phosphorus because he himself had had some difficulty in

* "The Significance of the Interpretation of the Chemical Analyses of Seepages," Journ. Inst. Petr. Techn., viii., p. 193, pt. 31, April, 1922.

† This should be contrasted with a Russian type of oil which contains a very low percentage of paraffins and is composed almost entirely of derivatives.

estimating the amount of phosphorus present when vanadium was also present, as the analysis was rendered difficult and complicated.

With regard to the analyses of the spirits mentioned by Mr. Kewley, he might add that he had carried out a large number of determinations on this point, which fully bore out what Mr. Kewley had stated. With regard to the naphthalene that Dr. Dunstan recorded as being found on the cracking of some of his oils, he had noted that, even with the Mexican oils, appreciable quantities of naphthalene, pyrene and chrysene were obtained at distillation temperatures at atmospheric pressures.

Dr. F. B. Thole expressed his interest in the inclusion by Mr. Kewley, among the characteristics of the benzine under discussion, of the compression ratio it would withstand. He could not agree with Dr. Ormandy, however, that this figure as it stood conveyed any real information as to the " detonation " qualities of the spirit since it held only for a specific engine running under specific conditions at a specific speed. If any of these factors were altered the compression ratio would also be altered. It did not even follow that relative figures of merit could be assigned to petrols by a test of this nature with a " standard " engine (in itself a very undefinable entity) since a totally different order of classification would result if the tests were conducted at various speeds.

He had in mind some recent experiments on a motor engine with the abnormally high compression ratio 7 to 1. It was found that a fuel containing quite a small proportion of aromatic hydrocarbons gave the highest power output when this engine was running under its normal conditions of very high velocity (about 4000 revolutions per minute). At one half this speed a quite different fuel containing a much higher percentage of aromatic hydrocarbons would have been required to maintain satisfactory running. In other words, the appropriate chemical composition of a motor spirit depends on the conditions of use, the design of the engine, its compression ratio, its normal speed, and the atmospheric conditions and the nature of the work the engine is called upon to do.

Mr. James Kewley, in reply, said he had only to reply to a few remarks by Dr. Ormandy and Dr. Thole on the subject of the efficiency of benzine in the motor engine and its relation to its chemical composition. They were fairly safe in assuming that if one benzine would stand a greater compression ratio under one set of conditions in one particular engine than another benzine, if the conditions were varied one would still get the same relative superiority or inferiority of the one benzine over the other, unless the conditions were varied perhaps to some abnormal extent. They were quite right in making that assumption if they applied it only

to such engines as were practically used to-day. In present day practice the compression ratios varied from 4 to 1 up to 5·8 to 1, in the case of Napier Lion, which he believed was the engine with the highest compression ratio at present made. When the Company with which he was associated started research with Messrs. Ricardo in 1919 on that subject they had as their aim the prediction of the behaviour of a motor spirit in an engine from an analysis of that petrol in the laboratory. They had long ago given up that as being a goal which it was utterly impossible to reach. It was next to impossible to obtain samples of all the various components which went to make up a motor spirit and to examine their individual behaviour in an engine. It would be quite difficult to deal with even the paraffins alone, because of the great number of isomers which might be present. This question was so complicated that it was only in a very general way that one could draw inferences as to the behaviour of motor spirit from its chemical composition, and the contents of paraffin, naphthenes and aromatics it contained. It was only with regard to the determination of the aromatics that they were on anything like safe ground at all, and even in this case, one could only give figures which were approximately correct if the final boiling point of the product did not much exceed 150° C.

The only satisfactory way of determining the maximum compression ratio which any particular motor fuel will stand, is that of determining it in an experimental variable compression ratio engine.

Dr. Dunstan in reply, said that Dr. Ormandy had implied that the control of the alkali concentration in the hypo chlorite process was somewhat difficult to accomplish. In point of fact no trouble arose from that factor and the refining of several hundred million gallons of distillates had proceeded smoothly and according to program. It was necessary to keep to a fixed alkalinity, but it was entirely erroneous to imagine that hypochlorites are particularly unstable. It is possible to separate crystalline sodium hypochlorite by the simple evaporation of a solution. Mr. McConnell Sanders had given him the impression that he was under the illusion that spirit treated with hypochlorite was liable to detonate. He would point out, as Dr. Ormandy had kindly reminded him, that Dr. Midgley, the principal American investigator on anti-detonation compounds and the inventor of "lead tetraethyl-gasoline" deliberately added carbon tetrachloride to the extent of 2 c.c. per gallon. As regards filming and the possible effects of phosphorus and other like components, he would say that they had taken the trouble to burn quite a considerable quantity of a kerosene which caused filming, and after analysing the films they had come to the conclusion that it was made up mainly of sodium salts. The bauxite filtration certainly did seem to eliminate

those dissolved salts, and thereby gave a non-filming kerosene. Mr. McConnell Sanders had raised the question of the nitrogen content. An approximate value could be obtained by calculating back from the coke analysis. He did not agree with Mr. Hackford that the crude oil was characterised by quite a small content of aromatics. It would be admitted that Maidan-i-Naftun oil contained a considerable quantity of these hydrocarbons. Concerning the forming of naphthalene in cracked spirit, he would point out that the cracking experiments referred to in the paper were carried out at quite low temperatures. By cracking at 700 C. the content of napthalene and aromatic hydrocarbons increased very considerably, but in a low temperature cracking operation, to find the residue of a fraction boiling up to 200° C. becoming solid owing to the recurrence of crystalline naphthalene was certainly very surprising.

The analysis of the ash for vanadium and phosphorus was conducted according to the following scheme:—

The ash was dissolved by fusion with sodium carbonate and the phosphorus and vanadium separated as lead phosphate and vanadate. This was decomposed by sulphuric acid, the lead sulphate filtered off and the filtrate evaporated, ignited and weighed as phosphoric acid plus vanadium pentoxide.

The vanadium was then estimated separately by reduction with sulphurous acid and titration with permanganate.

The two lecturers were then accorded a vote of thanks, and the meeting terminated.

The Wainwright Oil and Gas Area, Alberta.

By G. S. Hume.

Recently British Petroleums, Ltd., brought in an oil well near Wainwright from a sand 2019 to 2036 feet deep. Several wells have been drilled in this general vicinity, with the result that gas has been found in considerable quantities at several places and the outlook is favourable for further exploration.

As far as known the regional structure is a terrace, that is, a flattening of the general southwest dip over a considerable area. This produces a condition favourable to accumulations of oil and gas. It is also probable that minor structures, such as small domes or folds superimposed on the terrace structure, account for the localisation of the oil and gas into commercial pools. The edges of the terrace structure are not well defined, in fact not enough data are at hand from field work to do more than roughly outline the terrace; but from present information it is thought the western edge of the terrace extends north-westward from the vicinity of Hardisty to near Viking, where it turns more to the north. From Hardisty it probably extends south-easterly. Wainwright would thus be on the terrace at some distance from the western edge.

Other Wells in the District.

The Imperial Oil Co. drilled a well at Fabyan, six miles north-west of Wainwright, and in this well at a depth of 2727 feet a daily flow of 14,000,000 cu. ft. of gas was obtained. A small amount of oil was present, which the escaping gas sprayed over the derrick, giving rise to reports at the time that oil had been struck. Deeper drilling encountered water.

At Irma the Gratton Creek Oil Co. drilled a hole on Sec. 7, Tp. 45, Range 8, W. of 4th meridian. At a depth of 1620 feet 500,000 cu. ft. of gas was struck under pressure of 500 lbs.

The gas field at Viking is well known, there being a number of wells with varying but large supplies of gas. It is thought there are two gas horizons, one at about 2150 feet and the other approximately 2350 feet. The upper horizon gives the larger flow of gas. The structure in this field is supposed to be a minor dome-like fold on the terrace, which would explain the concentration.

At Vegreville a well drilled to a depth of 2000 feet found gas at 1360 feet amounting, according to reports, to 225,000 cu. ft. A little gas also came from a depth of 1870 feet.

In a well drilled at Birch Lake on Sec. 14, Tp. 50, Range 12, W. of 4th meridian, gas was found in a sand at a depth of 402 feet, the amount being 200,000 cu. ft. At a depth of 2018 feet 500,000 cu. ft. were obtained.

Thus it is well established there is a large gas field in the area to the north-west of Wainwright, and the oil well at Wainwright will likely lead to further exploration along the terrace structure. The oil at Wainwright is of a heavy quality, analysis showing it to contain but 2¼ per cent. of gasoline. While further favourable structures for accumulation of oil probably exist in this area, these will necessarily be of limited area and only the wells drilled on such structures can hope for success. In other words the producing wells in this, as in other areas, are localised. Owing to the heavy mantle of drift which covers the rocks over large areas in this district, structures are not easily located, so that it seems probable much test drilling will be necessary before the producing areas can be determined. Under such circumstances many wells which fail to bring in oil will undoubtedly be drilled, a fact which the investing public will do well to bear in mind.

The Oil Situation and Prospects in Canada.

By G. S. HUME.

DURING recent years active drilling operations for oil have been carried on in many parts of Canada both in well-established oil territory and in new prospective fields. Among these may be mentioned the producing fields of New Brunswick, the south-western peninsula of Ontario, and the sheep Creek field of Alberta, as well as exploration in the Prairie Provinces, British Columbia, and in the Mackenzie River District, North-West Territory. Recent developments concern particularly Ontario, Alberta and the Mackenzie District.

ONTARIO.

The oil fields of the south-western peninsula of Ontario date back to the early days of the oil industry in America. Of late years the production has, as a whole, shown a gradual decline with sporadic increases as new fields opened up. Late in the summer of 1923 a new oil well was brought in in Romney Township,

Kent County, the well being 3560 feet deep, and having an estimated initial producing capacity of two hundred barrels per day. The producing horizon or rock is what is known as the Trenton formation. Some previous drilling has been done in Ontario to test this formation, and from it is derived the oil produced from the Dover West field. Most of the oil production in Ontario, however, is from shallower wells from rocks of a younger age, so that this recent discovery opens up new possibilities in the Ontario fields. The Lima-Indiana oil field of Ohio and Indiana, U.S.A., which has been under development for almost half-a-century and is now approaching exhaustion, has had a good record of production from the Trenton formation.

Alberta.

Active drilling operations were carried on during 1923 near the International Boundary in Alberta, just north of the producing Kevin-Sunburst field of Montana. Two wells found showings of oil and active drilling is proceeding. No commercial wells have yet been reported. In the Kevin-Sunburst field the rocks are bowed up into a low dome from which the rock beds slope downwards in all directions. It is believed that the oil has migrated upwards along this slope in certain porous beds or "sands" until it has accumulated at the top of the dome-like structure, and as the Canadian area being tested is about 19 miles distant from the Kevin-Sunburst dome, no oil would be expected if the rocks had a uniform slope. It is known, however, that such a uniform slope does not exist, but there are minor flexures or warpings on the main dome structure, and these are as effective in arresting the oil in its migration up the slope as the main dome itself. It is on some of these subsidiary structures that wells are being drilled in Alberta close to the International Boundary. Since over the area as a whole the slope is downwards away from the main dome, it will be again obvious that the sands that produce oil in the Kevin-Sunburst field will be deeper below the surface in Canada and consequently deeper wells must be undertaken to reach them.

Further north in Alberta, British Petroleums, Ltd., in November brought in a well near Wainwright 120 miles east of the city of Edmonton. The depth of this well is 2036 feet, the oil being of a heavy quality. The well probably has an initial capacity of 60 to 100 bbls. per day, but has not yet been thoroughly tested. Several gas producing areas are located in this part of Alberta,

and the results from past drilling are encouraging for further exploration.

Fort Norman Area, Mackenzie River District, N.W.T.

In the Fort Norman area the Discovery well of the Imperial Oil Company, Ltd., brought in in 1920 was slightly deepened in 1923, an increase in flow now estimated at 100 bbls. per day being secured. Two other wells were drilled in 1923, one of which had a small showing of oil of no commercial value. The Mackenzie River District is far removed from railroad facilities, although three transportation companies operate steamers for three months during the summer on the Mackenzie as far north as the delta of the river at the Arctic Ocean. The possible oil fields in this area may, therefore, be considered of future rather than of immediate commercial importance.

The Significance of Nickel in Petroleum.

By Wm. Ramsay, F.I.C.

During the past few decades petroleum has advanced from a comparatively insignificant position to one of almost indispensable importance. Indeed, it is not too much to say, that were the supply to cease suddenly, many modern inventions would be rendered useless, and the world's progress set back for a considerable period.

Notwithstanding the fact that it is one of the earth's richest gifts, and is, in some respects, even more important than coal as a source of power, it must be admitted that the present knowledge of the subject is not so extensive as could be desired; more particularly is this true with regard to its nature and origin. While coal and other "organic minerals" bear in themselves some evidence of their genesis, petroleum on mere inspection carries nothing tangible to assist imagination, and all the conflicting theories which have been put forward from time to time to account for its formation are purely speculative and open to serious, if not fatal, objection; while some do not appear to have any scientific foundation.

Obviously, not one of the primary minerals, since it must have been formed after the earth became comparatively cool, the difficulty of accounting for the presence of such a highly complex organic body in the earth's crust is very great. Berthelot and Mendeleeff considered that it was the product of the action of steam or water on metallic carbides or acetylides, a view now generally discredited, owing to the improbability of such compounds existing in the earth.

Dumas, Rose and Bunsen thought it was derived from the hydrocarbon deposits of rock salt, an idea no doubt encouraged by the frequent association of salt with petroleum, but they did not indicate how these hydrocarbon deposits were formed, or even prove that they existed. Gregory and others assumed that it was the distillation product of coal, of which anthracite was the solid residue. Coal, however, is not usually associated with oil fields, and its distillation product is materially different from petroleum. On the other hand, Hackford[1], in a recent study of the subject considers that coal itself was formed by the gradual replacement of the cell content of wood and other vegetation by petroleum, a theory which later on will be shown to be improbable.

At the present day, the view most generally accepted by chemists and geologists is that like coal it is the decomposition product of pre-existing organic matter—*i.e.*, the remains of marine animals or marine vegetation.

In support of the animal theory, Kobyashi and others have produced petroleum-like bodies from fish oils. It is only right, however, to point out that fish oils do not differ materially from

those of terrestrial animal or vegetable origin, and that hydrocarbons, such as those that are contained in petroleum, have been produced in the laboratory from various other materials. An even more powerful argument against this theory is the impossibility of the existence of such vast accumulations of undecomposed animal remains, as would be necessary to account for even a small oil field. When marine animals die, either they decompose and are diffused in the ocean, or they become the food of other animals.

Among the adherents to the marine vegetation theory, Hackford* concludes, as the result of analyses of the ash of petroleum and on other considerations, that Mexican petroleum was formed from seaweed, and indicates certain algæ as being probably involved.

The arguments against the marine animal theory apply with almost equal force against the marine vegetation theory. The coastal growth of seaweed is confined within narrow tidal limits, since it cannot exist in deep water, and not even in tropical waters does it accumulate to any extent. While recent exploration has shown the Sargasso Sea to be of great extent, it has also shown that the pelagic seaweed is confined to isolated patches on the surface, and is in no place dense enough even to impede a swimmer.

A further argument against the organic theory is the almost entire absence of the nitrogenous and oxygenated compounds which are associated with the decomposition of animal or vegetable matter, and which usually break down into compounds quite dissimilar from petroleum.

Weak as the older theories were, they appeared the only possible solutions of the petroleum riddle. Conceived at a time when the horizon of chemistry was more restricted than at present, it was somewhat natural that the organic origin of coal, amber, marsh gas, etc., should dominate thought in this direction.

Within recent years, fresh discoveries in the domain of pure chemistry have shown that the older inorganic conception may not have been very far from the truth. Sabatier and Senderens, making use of the catalytic agency of nickel, have succeeded in hydrogenating unsaturated carbon compounds, a process which is not only of great scientific interest, but has become of considerable industrial importance. It has been demonstrated that carbon, carbon monoxide, and even carbon dioxide, can be hydrogenated by this means to form methane, acetylene or higher hydrocarbons, according to the temperature and pressure employed. It is true that carbon can be hydrogenated by heat alone, but equilibrium appears to be reached when the resulting gases contain about one per cent. of hydrocarbon. By using the nickel catalyst, however, the action goes to completion.

* The Significance of the Interpretation of the Chemical Analyses of Seepages. *Journ. Inst. Petr. Techn.*, Vol. 8, p. 193.

Since both hydrogen and carbon dioxide occur as natural gases, sometimes in the locality of oil fields, it appeared possible that these gases might form the starting point for the formation of petroleum. Sabatier and Senderens, by hydrogenating acetylene at high temperature and pressure, not only obtained a liquid corresponding in composition, odour, colour and fluorescence to a natural petroleum, but by varying the conditions as regards temperature, pressure and concentration, succeeded in synthesising petroleums of varying characteristics, such as appear in the different oil regions, and they seriously put forward the suggestion that the natural petroleums were formed in a similar manner.

Interesting as Sabatier and Senderens' theory might be, it remained, whilst unsupported by other evidence, only less speculative than those previously advanced, and it occurred to the writer that if their theory is correct, it would be reasonable to expect that the crude natural petroleum might carry to the surface of the earth some trace of the nickel catalyst. On examining the ash of a number of fuel oils from various parts of the world, this was found to be the case. In addition to nickel, many of these oils carry traces of other metals such as vanadium, copper, lead, etc., several of which are also of catalytic significance. The following table shows the nickel content of a number of authentic petroleums and some associated bodies expressed as parts per million :—

Source.	Consistency.	Ni, parts per million.
Mexican	Semi-solid	83
"	Thick	49
"	Medium	67
Texas	"	44
"	"	71
"	Thin	68
Californian	Medium	49
"	Thick	63
Roumanian Ostatki	Semi-solid	17
Persian	Medium	12
"	Thin	93
"	"	4
Burmah	"	12
"	Medium	8
Java, Surabaya	Thin	3
Borneo, Balik Pappan	"	1
" (Mixed)	"	3
Asphalt, Trinidad		194
" Swiss		120
" rock (unknown)		14
Gilsonite, California		133
Petroleum pitch, U.S.A.		240
Ozokerite (Germany ?)		trace
" Refined German		nil

The above oils are the crude petroleums from which the more volatile fractions have been removed by distillation and are known as fuel oils or Diesel engine oils.

So far, all the oils examined have shown the presence of nickel. Those of low viscosity generally show least, and some of the East Indian oils show so little that its presence might easily be overlooked. In some cases, upwards of two kilos. had to be ashed in order to obtain sufficient material for an estimation. One sample of Borneo oil gave less than one part of nickel in ten million of oil, while a Persian oil in which nickel had been overlooked, showed, on repetition, a quantity much smaller than in the Borneo sample.

At first, the writer was of the opinion that such small amounts of nickel would seriously embarrass Sabatier and Senderens' theory, but Dr. R. Thomas, one of the leading workers in hydrogenation problems, points out that even if oils totally devoid of nickel were found the theory would not be invalidated, since it is now known that very much smaller quantities of the catalyst are required than was previously thought necessary, and in some cases it might be of such a nature that it would be retained in the earth by filtration or sedimentation.

Attempts to ascertain the condition in which the nickel exists in the oil have, so far, proved abortive, but there are indications that it may be colloidal, in which case it would act as a powerful catalyst. There are also indications that it is associated with the asphaltic portion of the oil, but this point requires further investigation. It is noteworthy in this connection, that the more asphaltic oils as a rule carry most nickel, and the solid asphalts are comparatively rich in it.

Although in all the petroleums examined the nickel appears to be in the colloidal state, this does not preclude the possibility that in some, or indeed in all oils, it may also exist in the crystalloidal condition, and since it is known that the laws of catalysts are different for each form, there exists the possibility that the presence or absence of unsaturated hydrocarbons may depend on the relative amounts of each modification present in the various oils.

The presence of nickel in petroleum has been previously noted, but its significance as a possible factor in the formation of the hydrocarbons appears to have been overlooked. Hackford*, in the case of Mexican oil, considers that it has been absorbed by the sea-weed from the sea-water. The ash of Laminaria *digitata*, and of Fucus *vesiculosus*, however, show no trace of the metal, although the latter algæ frequently shows a slight trace of copper, probably due to local circumstances. A large sample of Irish kelp gave the same nagative result. More recently, Guthrie† reported nickel in the ash of Egyptian petroleum, but made no further comment on it.

* See note, p. 88.

† Heavy Grade Egyptian Crude Petroleum. *Journ. Inst. Petr. Techn.*, IX., p. 212, 1923. See also Dunstan, *Journ. Inst. Petr. Techn.*, IX., p. 235, 1923, and this *Jnl.*, pp. 55-56.

In view of Hackford's theory of the formation of coal from petroleum, a number of British coals have been examined for nickel, but in one case only has the slightest trace of the metal been found, and since a second sample from the same source gave a negative result, its presence was probably adventitious. These results tend to divest this theory of its probability.

The writer has made use of the presence of nickel to show that the carbonaceous deposits in the cylinders of Diesel engines are due to the fuel rather than to the lubricating oil. These deposits provide sufficient ash to demonstrate readily the presence of the metal, even when it is difficult to detect it in the laboratory oil sample, such as in the Borneo oil previously mentioned.

Nickel is not a ubiquitous element. Its general occurrence in the mineral hydrocarbons from such widely different sources can hardly be a coincidence, and lends very strong support to Sabatier and Senderens' theory. The earlier theories of petroleum formation owed their weakness to the assumption that it could only be of organic origin, while the theory under discussion has the advantage that it allows of a purely inorganic origin, which is more in accordance with geological conditions. It also holds out the hope that, where circumstances are favourable, the formation may be taking place at the present time.

Investigations into the Protection of Oil Storage-Tanks from Lightning.

By W. R. MACDONALD, M.I.Mech.E., A.M.I.E.E.

THE important problem of protecting oil storage-tanks against lightning has received a good deal of attention from time to time, and of recent years H.M. Government in particular has had the matter under close consideration. In 1919 an important Bulletin, "Inquiry into the Protection of Oil Storage-Tanks against Lightning," was published by H.M. Petroleum Executive with the object of disseminating the best available information on the subject to all concerned. A perusal of this Bulletin shows that considerable diversity of opinion exists in the minds of the technologists and men of science whose views were canvassed as to the precautions which should be taken to prevent damage by lightning, and, indeed, whether lightning conductors should be used for this purpose at all.

The matter is of so much importance to all interested in oil storage, especially in the tropics, that advantage was taken of an opportunity which presented itself, in connection with investigations of a geological nature into the selectivity of lightning, to put some of the more debatable points to experimental proof.

DETAILS OF THE APPARATUS USED.

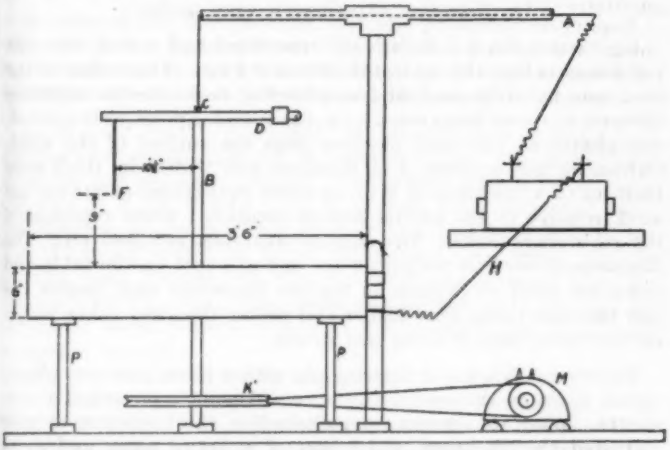
The apparatus consisted essentially of a high-tension coil capable of giving a 2-ft. spark and energised by means of an electrolytic interrupter which passed a chopped direct interrupted current to the primary windings of the coil. The value of the current taken was 15 amp. 100 volts.

The high-tension secondary terminals of the coil were connected to a suitably constructed insulated table on which the experiments were conducted. The arrangement is shown in the accompanying diagram.

A represents one of the high-tension leads, threaded through a glass tube and supported and held in position by a glass standard. The end of this wire furthest from the coil is turned down at right-angles to its length, and, being pointed, centres itself on a centrally placed countersunk stud situated on the upper end of a revolving shaft *B*. From the stud *C*, and in contact with it, is a second wire which is laid along the revolving balanced arm *D*, and, being likewise turned down at its end, terminates in a point *F*.

From this point *F* the discharge takes place across the air gap, and on to the table, which is insulated by supporting pillars of ebonite *P*. The earth return is completed by leading the other h.t. wire *H* straight from one of the h.t. terminals on the coil to wire netting of 2-in. mesh laid on the bottom of the table and cut exactly to its shape.

The diameter of the table was 3 ft. 6 ins., the radial distance of the sparking point from the vertical axis being about 10½ ins. The sparking distance from the point *F* to the table was made adjustable between 6 and 9 ins., according to what was required. In order to effectively insulate the revolving spark point from earth, the



HIGH-TENSION DISCHARGE APPARATUS FOR LIGHTNING EXPERIMENTS.

revolving axis which actuates the carrier arm *D* consisted of an upright ebonite rod 1½ in. diameter passing through the centre of the table and made to revolve by means of a wooden pulley *K*, belt-driven by an electric motor *M*, which was under control as regards speed.

In carrying out an experiment the table was covered with fine clean sand up to a depth of about 3 ins. In order to eliminate large or uneven particles and to get uniformity as far as possible, the sand, before being placed on the table, was passed through a 40-mesh sieve.

Under these conditions, when the current was switched on to the coil, the spark jumped from the revolving spark-point *F* to earth, and thus represented a lightning discharge. The speed of

the revolving spark point was controlled in order to represent a thunder cloud passing over any particular spot on the surface of the "earth," and, in so doing, the movement set up in the air agitated the immediate neighbourhood sufficiently to disperse any ionised condition that might have become established, and thus cause a preferential descent of the lightning to any one spot.

As far as could be arranged, all experimental conditions were chosen to simulate natural conditions, and when this was considered to be satisfactorily attained a preliminary run was made to precede the actual experiment in order to insure that no undue influences had been overlooked which might build up a preferential potential difference at any one spot, thus giving a false reading as regards selectivity. The following experiments were made:—

Experiment No. 1.—River sand was sifted and spread over the wired floor of the table up to a thickness of 3 ins. The surface of the sand was carefully smoothed and levelled to insure the sparking distance all round being equal—*i.e.*, the sparking point, as it rotated, was always at the same distance from the surface of the sand. Galvanised iron washers, $\frac{3}{4}$ in. diameter and 3/16ths in. thick were built up to a thickness of $\frac{3}{4}$ in. at three equidistant points on the sand, relative to the central axis of rotation. These represented the oil storage-tanks. The current was then switched on. The discharge showed no preference for any one spot on the table and expended itself at random in various directions and, despite the fact that the tanks were higher and nearer than any other points on the table, none of them was struck.

Experiment No. 2.—A drawing-pin with a brass base was placed upside down on the sand. The upturned point represented a conductor. When the current was switched on, this conductor at once attracted the discharge, which was of a heavy order and quite different from the thin indifferent flashes which were produced when no special attraction point was erected. The secondary discharge was also heavy. Sparks played around the tanks with a corona effect, and some of the sparks established definite secondary arcs with the so-called "tanks."

Experiment No. 3.—The washers, representing the oil tanks, were collected together and grouped round one spot on the sand to represent a tank farm. Each tank was then connected by a metallic ring representing the pipe-lines leading to a common service. The lightning conductor (drawing-pin) was now placed in the centre of the farm, and not effectively earthed. Under these conditions the pipe-line and tanks all became alive with sparks showing secondary discharges, some of which spread to a considerable distance.

Experiment No. 4.—The conductor was earthed; that is to say it was placed on a copper disc which itself was connected to the sand by a piece of copper wire attached to it, the wire being inserted into the sand to a depth of 2 ins. Under these conditions, when the current was switched on the secondary discharges ceased; the whole tank farm was cleared of sparks, and the discharge went straight to earth through the conductor.

Experiment No. 5.—A small projecting point was placed on one of the oil tanks, and this tank was not effectively earthed. In every case the discharge was attracted to this particular tank, and through not being properly earthed it was invariably enveloped in a mass of sparks.

Experiment No. 6.—The tank with the projecting point used in Experiment No. 5 was earthed. The discharge was again attracted to the tank, but in every case it was now of a much heavier order, and there were no secondary sparks in the immediate vicinity.

Experiment No. 7.—The tanks were grouped to represent a tank farm as in Experiment No. 3, and connected by "pipe-lines," none of which was properly earthed. A conductor was placed at radial distance of 4 ins. from a vertical dropped from the spark point, the distance of the sparking point to the sand level being 6 ins. The conductor was $\frac{1}{4}$ in. above the normal sand level. On the current being switched on, the discharge was diverted from the vertical over the tops of the tanks and went to earth through the conductor without any evidence of the discharge being scattered or sparks formed.

Conclusions to be Drawn from the Foregoing Experiments.

Experiment No. 1.—The natural deduction here is that an oil tank with no projecting points has no inherent susceptibility of being struck by lightning.

Experiment No. 2.—This result appears to be in conflict with generally accepted opinion. The silent discharge on which hitherto so much dependence has been placed to relieve potential difference showed itself powerless to cope with this relatively large potential difference.

Experiment No. 3.—This experiment seems to emphasise the danger of having any form of lightning conductor, whether to attract or disperse the potential difference, unless every precaution is taken effectively to earth the conductor. In a dry country with sandy soil it must be observed, however, that to earth the conductor is not so easy as might be supposed.

Experiment No. 6.—This clearly shows the necessity of insuring a perfect earth being established when points are used on tanks; otherwise a secondary discharge will almost certainly take place.

Experiment No. 7.—This final experiment is most important, as it seems to point to the complete protection afforded by the use of one centrally placed conductor, but it must be of sufficient carrying capacity, of the requisite height, and effectively earthed.

Summary.

Oil tanks have a much better chance of not being struck by lightning if they are left to themselves without the erection of any special contrivances intended for protection purposes. If a lightning conductor is used, however, it is better to concentrate on one spot, erect the conductor by itself, and take all precautions to earth it properly.

In coming to this conclusion, it may be permissible to suggest the following explanation of the curious effects sometimes exhibited by a lightning discharge in destroying masonry and other solid structure, whilst passing down a conductor to earth. It would seem that the destruction would not occur if the conductor were erected at some little distance from the object it was intended to protect.

It must be remembered that in a lightning discharge there is an oscillating current of extreme rapidity with a wave length of probably $\frac{3}{8}$ mile and frequency of about 500,000 cycles per second. This, acting inductively on neighbouring objects, whether of a metallic nature or not, endeavours, by inductive linkage, to make them oscillate at the same frequency. In the effort to make the masonry or other material synchronise, which, probably, having a different time period of its own it is unable to do, a disruption takes place by the lightning removing the masonry; or, if this is impossible, by reason of the solidity of the material, the discharge selects a freer path of its own, and leaves the conductor altogether.

It is for this reason, in addition to what has been shown by experiment, that a centrally placed conductor has many advantages and, if properly earthed, is almost certainly the best possible protection to a group of storage-tanks.

From the results of experiment No. 7, an approximation can be arrived at as to what should be the dimension of a metal conductor as regards height, etc. The area required to be protected must be previously known as well as the height of each tank. The tanks should have no projections. Taking a general case, however, it appears that a conductor over 50 ft. high would protect a circular zone of $\frac{1}{4}$ mile in diameter on which were tanks grouped as in a

tank farm, each tank being taken as of 45 ft. high. The centre of the storm overhead is taken as having an elevation of 1000 ft., this being the probable height from which most flashes come to earth in their final descent.

Referring to the above, the following contributions have been received :—

From Mr. H. BARRINGER :

The conclusion to be drawn from description of the experiments carried out with electrical discharges appears to be that, provided the earthing of tank is efficiently carried out, there is no danger of the tank itself suffering. It has been said (Sir O. Lodge) that the most efficient protection against lightning that could be afforded to any object would be to place same in a structure resembling a wire parrot's cage, the cage being effectively earthed. A storage tank partially fulfils this requirement. Any projecting points appear to be liable to attract the flash, and as most tanks are fitted with handrails surrounding the circumferential edge sometimes carried up to centre, these may be a source of danger unless care is taken that the stanchions have a perfect metallic connection to tank plating.

It must also be borne in mind that many cases of tank ignition during storms are due (especially in tropical or semi-tropical climates) to the ignition of the gas-laden atmosphere surrounding the tanks, and not to the tanks themselves being struck, in which case the central protector suggested instead of constituting a safeguard would become a source of danger by attracting a discharge.

From Mr. JAMES KEWLEY :

I feel that it is very risky to draw conclusions from a small scale experiment of this kind and to use them to interpret the conditions prevailing in actual practice in a thunderstorm. There is no doubt that tanks and pipe-lines must be well earthed. I do know of occasions when sparks have been drawn from tanks on ordinary foundations connection to pipe-lines, and this is a country where the atmosphere was by no means dry.

From Mr. HUBERT MAY :

Mr. W. R. Macdonald's investigations into the protection of oil storage-tanks from lightning are most interesting and instructive, but I think he overlooks the fact that it is claimed that many oil tanks are fired by the ignition of escaping gas 100 ft. or more above the tank. This applies more to light oil storage, but even heavy oils with a small percentage of light fractions give off sufficient gas to endanger the bulk.

Although the roof jointing can be made perfectly gas-tight, a valve or valves are of necessity fitted in the roof to relieve the pressure caused by evaporation due to sun heat, which valves pass the light gases and result, in a lesser degree, in similar conditions prevailing as with a leaky roof. Storm conditions usually prevail in a still atmosphere, thereby allowing the air to become sufficiently saturated with gas to cause explosion or ignition.

A means of avoiding this dangerous state in localities where storms prevail is to connect the relief valves to pipes fitted with one or more gauzes to prevent back-fire, through which the gases are conducted to a safe distance and released to atmosphere or retained by absorption or even collected in a receiver and returned to the tanks during the night when the falling temperature creates a partial vacuum.

I am of opinion that if conductors are installed they should be placed well away from the tanks and be three or four in number, with a view to destroying a potential by brush discharge or by intercepting lightning before it reaches the tanks, in an endeavour to prevent the flash from passing through a gas-impregnated zone.

If such an arrangement of conductors, well earthed as is pointed out by the author, is not erected, I consider that a tank farm is safer without any protection of the kind whatever.

To avoid difference in potential by induction between plates a method has been adopted in America known as the Dodd system, whereby the tank roof is covered with a netting, each plate being in metallic contact and the netting earthed at several points; thus a defective roof with gaps between the plate joints has all its plates earthed, thereby avoiding a spark over the gap. Tanks fitted in this way sometimes command better terms from insurance companies than those with no such protection.

I think the best protection against fire in tanks is to erect and maintain the roofs gas-tight leading off bleeder lines from the relief valves to a safe distance.

The following contribution has also been received:—

The revolving table introduced by the experimenter for the purpose of imitating an approaching thunderstorm means a new interesting feature and an ingenious improvement on similar experiments said to be carried out previously. Nevertheless, the conditions prevailing during the experiments are not the same as those we find in actual practice when a thundercloud passes over a tank farm. The experiment is carried out with a constant and comparatively low potential (6 to 9 inches spark), high enough, however, to enable a spark discharge between metal point and table. Against this, when a thundercloud approaches a tank farm, its potential is supposed to increase gradually until a dis-

charge takes place in the shape of a lightning spark, the length of which, however, is far greater than it could possibly be according to the prevailing difference in potential between the thundercloud and the earth. Thus, when a thundercloud approaches a tank farm, inductive phenomena of quite another nature and grandeur may and will prevail than can be imitated with the experimental set described.

The experiments lead to the conclusion that tanks and pipe-lines have to be earthed, which is in conformity with practical experience.

However, the conclusion that a central lightning conductor, a few feet higher than the roofs of the tanks, would give effective protection for a tank farm, is not sustained by actual experience with lightning conductors. J. d. B.

The Reaction of Cracked Spirit with Formaldehyde.

By W. R. Ormandy, D.Sc., F.I.C., F.C.S., and E. C. Craven.

The determination of the amount of unsaturated hydrocarbons in petrol still being an unsolved problem, some experiments were carried out for the purpose of determining whether these unsaturated hydrocarbons could be quantitatively condensed with formaldehyde. Some preliminary experiments showed that if a cracked spirit is refluxed with formalin in the presence of an electrolyte, brown resins were formed varying in consistency from a sticky oil to hard gums. The refluxed mixture which was used in the bulk of our experiments contained :—

5 grams petrol.
5 c.cs. formalin.
5 c.cs. hydrochloric acid (sp. gr. 1·16).

The length of time required for refluxing was determined by experiments on a particular cracked spirit. It was found that the following amounts of resins were formed :—

1 hour	refluxing . . .	29·5 per cent.
2 hours	,, ...	35·7 ,,
4 hours	,, ...	35·8 ,,

The mixture, after refluxing, was evaporated down on the hot plate, and finally on the water bath until practically the whole of the visible aqueous liquor had gone and the resins were then dried in the water oven. In most cases it was found that the resins lost steadily in weight at the rate of 0·1 to 0·2 per cent. per

hour after the smell of hydrochloric acid and formaldehyde was no longer observed. This appears to be due to volatilisation of the resins themselves, particularly when of the softer type. A standard period of three hours' drying was therefore adopted. Some results by this method were as follows :—

Sample.	Resins. Per cent.	Bromine No. Per cent.
Petrol No. 1	0·5	1·0
„ No. 2	0·5	2·3
Benzene	0·5	0·2
Toluene	1·5	nil
Xylene (commercial)	2·6	0·7
M-Xylene	6·8	nil
Cyclo hexane	0·3	nil
Cracked Spirit No. 1	35·8	76·2
„ „ No. 2	6·9	21·6
„ „ No. 3	37·2	70·6
„ „ No. 4	27·5	64·5
„ „ No. 5	4·2	20·0
„ „ No. 6	54·0	83·2
„ „ No. 7	26·2	59·3

An experiment was also made with No. 1 Cracked Spirit in order to determine if ammonia would serve as a condensing agent, but only 9·5 per cent. of resins were formed, and these did not appear to be any harder or less volatile than when acid was used.

An experiment was made, taking a larger quantity of No. 7 Cracked Spirit, in order to examine the residue after the formalin treatment. The residual spirit was steam distilled off, washed with ammonia and water to remove acid and any free formaldehyde. This residual spirit amounted to 86 per cent. by weight on the petrol taken. The resins formed were 36 per cent. The Bromine number of the residual spirit came out at 52·9, so it is obvious that under the conditions of our experiments only a mere fraction of the unsaturated hydrocarbons, measured by Bromine absorption, is converted to resins. A repeat of the resin test on the residue of the spirit gave 12·7 per cent. of resins, so that presumably the condensation will have to be repeated many times before the bulk of the unsaturated hydrocarbons is removed. An attempt was made to increase the yield of resins by increasing the formalin in the reflux mixture, but when double the quantity of formalin was employed only 19·3 per cent. was formed, as against 26 per cent. with the normal quantity. An experiment using paraformaldehyde and alcohol in place of formalin gave a still lower result, namely, 4·7 per cent.

It is somewhat remarkable that meta-xylene should give a condensate. It will be noticed that most of the resins formed, adhering to the one method, are very roughly proportional to the Bromine numbers.

Determination of Naphthenes in Petroleum Spirits.

By W. R. ORMANDY, D.Sc., F.I.C., F.C.S., and E. C. CRAVEN.

PETROLEUM spirit is usually considered as containing four classes of constituent hydrocarbons :—

1. Paraffinoid.
2. Aromatic.
3. Unsaturated.
4. Naphthenoid.

It appears to be the custom to regard all bodies not dissolved out by sulphuric acid of 98 per cent. stength as being either paraffins or naphthenes. In this sense only the saturated hydro-aromatics, as for example cyclohexane, will be included in the naphthenes, the less saturated compounds being dissolved out. Strictly speaking, the aromatic hydrocarbons are unsaturated bodies in that the addition of hydrogen atoms can be made to their molecules without destruction of the nucleus. The term unsaturateds, however, appears to be confined to bodies of the olefine or diolefine type containing one or more double bonds, and which absorb bromine readily under the conditions of the usual tests such as Hanus or Wij's. There appears to be no satisfactory method for the determination of the proportion of unsaturateds present in a petroleum spirit, but we have found their presence to be indicated by the fact that on refluxing with formalin and hydrochloric acid large quantities of resins are formed. The results obtained will be dealt with in another note.

Confining our attention to the question of the determination of the proportions of paraffins and naphthenes present in a given spirit, obviously the first thing to do is to obtain the mixture of these two bodies left after sulphonation with 3 volumes of 98 per cent. sulphuric acid as in the Thole's method for the determination of aromatics (*J. Soc. Chem. Ind.*, 1919, 39 T).

Aniline-Point Method.

Tizard and Marshall (*J. Soc. Chem. Ind.*, 1921, 20 P) propose a method for the measurement of naphthenes based on the aniline-point of the washed spirit. The average naphthene has an aniline-point lower than a paraffin of similar boiling-point by an amount which is a function of the boiling-point. The aniline-point of all paraffins being 70° C., the fraction of the washed spirit boiling

up to 95° C. contains naphthenes which lower the aniline-point at the rate of 0·4° C. per 1 per cent. For the fraction 95 to 120° C. the figure is 0·3° C., and for the residue 0·2° C. For rough estimation it is stated to be sufficient to take the mean figure 0·3. In the succeeding work, where determinations have been made by the aniline-point method, we have used this mean figure in order to avoid the fractionation, which means that very large amounts of the spirit and sulphuric acid have to be dealt with (*J. Inst. Petr. Tech.* 8, **34**, 591, 1922). The method is admittedly only an approximate one, and is based on the experiments of Tizard and Marshall and also of Chavanne and Simon. It would obviously be better if we knew the mean boiling-point of all the naphthenes present and the lowering of aniline-point corresponding to this mean naphthene, always supposing that a smooth relation exists between the mean boiling-point and the depression of aniline-point.

Specific Gravity Method.

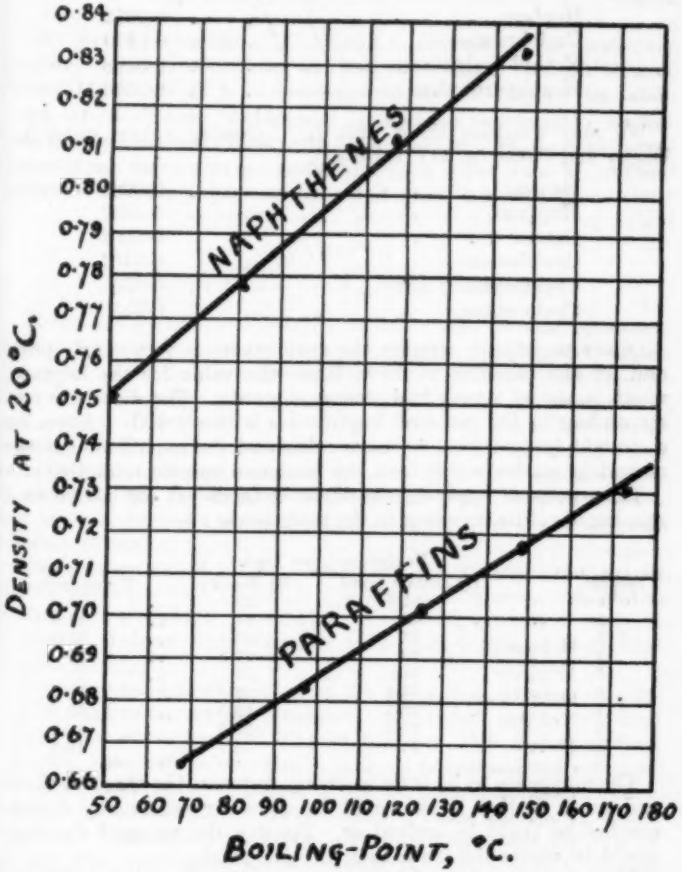
It is usually accepted that the average naphthene found in a petroleum spirit is 0·1 higher in specific gravity than a paraffin of a similar boiling-point. This obviously gives a method of determining the naphthene present in a paraffin-naphthene mixture. In the present work we have determined the density at 20° C of the washed spirit, and then carried out an Engler distillation on 50 c.c.'s, the mean boiling-point being determined by taking the average of the drop and dry point and the temperature of distilling of each 10 per cent. If the density at 20° C. of the normal paraffins be plotted, it will be found that they fall more or less in a straight line. The figures given in the literature are extremely diverse, but the most reliable figures we have been able to find are as follows :—

	b.-p.	20° C.
Hexane . . .	68·9	0·6644
Heptane . . .	98·4	0·6836
Octane . . .	125·5	0·7028
Nonane . . .	149·5	0·7177
Decane . . .	173	0·730
Cyclopentane . .	50·5	0·7508
Cyclohexane . .	80·5	0·7780
Cycloheptane . .	117·5	0·813
Cyclooctane . .	147·5	0·834

Constructing a curve from the normal paraffins, the density of the mean paraffin corresponding to the mean boiling-point determined was found; this subtracted from the actual density of the washed spirit and multiplied by 1000 gives the proportion of naphthenes present calculated on a straight line basis.

Refraction Method.

According to the simple additive theory the specific refractivity of all naphthenes of the general formula C_nH_{2n} should be the same, whilst paraffins of a similar boiling-point have a higher refractivity owing to the greater proportion of hydrogen present. For simple



bodies like hydrocarbons we may expect that the observed value of the refractivities will agree fairly well with the calculated ones even using the formula of Gladstone and Dale as suggested by Engler and Höfer (Vol. I., p. 117). Here, again, unfortunately,

the published figures are extremely diverse and the differences are too serious to allow of founding a quantitative method. By actual measurements, however, on laboratory specimens, made by means of an immersion refractometer, we find the following values for the specific refractivity on the Gladstone and Dale formula :—

Heptane	0·5672
Cyclohexane	0·5479
Methyl cyclohexane	0·5498
Hexahydroxylene	0·5516

We may compare these with the following values given by Engler and Höfer (p. 117, table 43).

Hexane	0·5689
Heptane	0·5697
Octane	0·5664
Cyclohexane	0·5467
Cycloheptane, abt.	0·555
Cyclooctane, „	0·555

Of our naphthene samples the cyclohexane is very nearly pure, and for the paraffins we have taken the value for the heptane, which is also of a very high degree of purity. The difference corresponding to 100 per cent. naphthenes is thus 0·193. Assuming a straight line relation, we have calculated the naphthene content of various washed spirit from the measured specific refractivity.

The results of applying the three methods set out above to a number of spirits are given in the table below :—

	Naphthenes per cent.		
Sample.	By aniline point.	By density.	By refraction.
1	31·5	25	30
2	43	44	44·5
3	47	32	33·5
4	20	22·5	33
5	34·5	27	33
6	63·5	64	78·5
7	20·5	19·5	25
8	31·5	29·5	39·5
9	17	16	16·5

There appears to be little to choose between the three methods, and much further work would be necessary before any definite conclusions could be arrived at. Possibly the mean of the three would be nearer the truth than any one singly.

This note, together with the one on "The Reaction of Cracked Spirit with Formaldehyde," is extracted from the work on fuels which is being carried out for the Distillers Company, Ltd., and the Fuel Research Board of the Department of Scientific and Industrial Research, to whom the authors are indebted for assistance.

STUDENTS' SECTION.

LONDON BRANCH.

THE Second Meeting of the London Branch of the Students' Section of the Institution was held at Aldine House, Bedford Street, London, W.C. 2, on Tuesday evening, November 27th, 1923.

Mr. H. G. Austin (Chairman), in opening the meeting, called attention to the last issue of the Journal (No. 39), in which the Rules of the Section were printed, and then called upon Mr. Albert Millar to read his paper, an extract of which follows :—

SWABBING.

By ALBERT MILLAR, A.M.I.Mech.E. (Member).

There are several methods by which crude oil can be raised to the surface from wells, depending upon existing conditions. When the depth does not exceed 3500 feet, and where large quantities of sand have not to be raised, deep well pumps are most generally used. Wells in which large quantities of sand have to be raised with the oil are generally exploited by the method known as "bailing," but this can only be practised when the diameter of the borehole is 8 inches or upwards. The "airlift" method can be used for wells of smaller diameter, but this is a costly and difficult process.

The production of oil by "swabbing" is chiefly practised in the Galician oil-fields, although it is used in Rumania, the United States and elsewhere. Swabbing is the only practical method of raising oil from small-diameter wells from depths of from 3000 to 6500 feet.

Swabbing has a suction effect on the well and an average vacuum of 8 lb., and under certain conditions even higher, can be obtained during the lift. Shows of oil and gas met with during drilling are often cased off because the quantity is not considered sufficient for exploitation, but this should not be done without the show being exhaustively tested by the swab. Cases are known where compact sands drilled into gave shows of only a few buckets of oil, but after continued swabbing produced as much as 50 to 70 tons daily.

The best results with the swab are obtained where the production is derived from compact sandstones, crevices or fissured beds, where the channels are liable to become choked by sand or paraffin wax ; even in somewhat loose sands swabbing may be employed

if strainers are used. In cases where wells have practically ceased to produce, a new lease of life can be given by the discriminate use of the swab.

For wells over 3000 feet deep, where the swab will be required for regular production, the following plant is necessary :—

Winding Engine.—This is similar to a colliery winding set, and made in three sizes, designed to develop the respective horse-power at 80 r.p.m. with a steam pressure at the engine of 90 lb. per square inch and a 50 per cent. cut off. The dimensions are as follows :—

H.P.	Diam. of Cylinder. m.m.	Stroke. m.m.	Diam. of Drum. m.m.	Width of Drum. m.m.
90	300	400	800	1000
120	350	500	1000	800
300	400	600	1600	750

The size of the winding plant depends on depth of well, size of casing, and weight of oil to be lifted. For wells 3000 to 4000 feet deep, with 4- or 5-inch casing, and where not more than 200 to 300 kilos. of oil have to be raised per lift, the general rule is to use the 90 h.-p. set ; for wells 4000 to 5000 feet deep, with 4- to 6-inch casing, a 120 h.-p. engine is taken, and the oil lifted would be 250 to 350 kilos. per lift ; and for wells 4000 to 6000 feet deep, producing 400 to 700 kilos. of oil per lift, a 300 h.-p. winding set is selected. In taking these figures as a basis it is assumed that 6 to 10 double trips per hour will be made, depending on the depth of the well.

The winding drum is fitted with two copper-sheathed brakes, operated by both hand and foot, and these are intended for emergency use only. On the downward journey the engines are pulled round by the weight of the descending tools and rope, and steam is not admitted to the cylinders, but air is sucked in through the exhaust and throttled at the outlet, thus converting the engines into compressors. It is important that a small quantity of steam should be by-passed into the cylinders to keep the air moist. The winding drum is keyed on to the crank-shaft and a depth gauge, fitted with a gong and four striking gears, is connected to each set, so arranged to give a signal when the swab is 100 metres from the top or the bottom of the borehole, and a second warning when the swab has reached the limit for which it is set. The maximum speed of the larger winding set is 80 to 110 r.p.m., and of the smaller types up to 220 r.p.m.

The power required for swabbing depends on depth, diameter of casing, and amount of oil to be lifted. Taking a 1400 metre well as an example, with 6-inch casing and 200 kilos. of oil lifted per run, the maximum power required is at about 1100 metres, when the average speed of the rope is 9 to 10 metres per second,

the engine output then being 250 h.-p. The minimum h.-p. required is about 50, when the swab is approximately 150 metres from the top. The mean engine output throughout is about 180 h.-p., and the average time to lift the swab 1400 metres 3 minutes, the time to descend 1400 metres averaging 3.25 minutes.

Boilers.—It is advisable to erect a boiler of such dimensions as to be able to cope with all calls put upon it, that is, not only for swabbing, but for heating the oil in winter time, running the pumps, electric lighting set, and heating the buildings.

Swabbing Tubes or Casing.—The only casing that can be used for swabbing is that which gives a flush inside joint. The internal diameter should be 5 or 6 inches, and the casing should be solid drawn from steel, with a tensile strength of 55 to 65 kilos. per square millimetre, and 15 to 25 per cent. elongation. The inside finish must be smooth, the thickness of the wall being generally 7 to 8.5 m.m.

Swabbing Rope.—It is general practice to use an 18-m.m. diam. rope consisting of 6 strands of 19 wires each over a hemp or manilla core. For shallower wells a 16-m.m. wire rope is often employed. The rope has to endure more hard work and mishandling than any other part of the plant, and has to run at very high speeds, and should be constructed from steel, having a tensile strength of 120 to 130 kilos. per square millimetre.

Derrick Headwheel.—This wheel should have a diameter of at least 1000 millimetres, measured at the inside of the grove, and the diameter of its axle journals should be not less than 100 millimetres. The axle should be of mild steel, case hardened at the journals, and the wheel itself of fine-grained cast iron. The most important part is the grove, which is generally V-shaped, and an improved design is now coming into use in which it is U-shaped, with a shallow channel cut for the rope at the base of the U. With this design the rope lasts three times as long, and the wheel five times as long, as with the V shape.

Swabbing Tools.—Connecting between the swabbing rope and the swabbing tools is made by means of a ball-bearing swivel. To the swivel a sinker bar is connected, having a diameter of 70 to 80 m.m. and a length of 7 to 8 metres, and to this is screwed a pair of swabbing jars, below which comes the swab.

The swab is a plunger fitted with a ball valve, and its working barrel is the casing column. A rubber ring is used as a packing, and is kept expanded tightly in the casing by two powerful helical springs. These rings last from 10 to 20 days or even longer, and those made containing 50 to 60 per cent. pure rubber give the best results.

Useful Points on Swabbing.—The shoe of the casing should be bell-mouthed to allow for the easy entry of the swab.

The casing-shoe should be not more than 3 to 5 metres from the bottom of the borehole. This prevents caving, and should the swab become unscrewed it does not fall off to the side.

The rubber packing ring should be expanded about 5 to 7 m.m. larger than the inside diameter of the casing.

The swab should be run slowly into and through the oil column on the downward journey. Otherwise back pressure is put on the oil-sand and the rope may be damaged.

The swab should be allowed to run below the casing-shoe to permit a free influx of oil into the casing, especially in the case of a sluggish well.

Before the upward journey the swab should remain below the casing-shoe for ½ to 2 minutes to allow the oil time to collect.

In cases where the formation allows, the speed of the swab should be increased five to ten seconds after commencing the upward journey until the maximum is reached, only slowing down at about 100 metres from the top.

The swab should be withdrawn from the casing only when it is necessary to control the rubber packings.

The speed at which the swab is run depends on depth of well and diameter of casing, quantity of oil produced, porosity of producing bed, quantity of paraffin wax in crude, amount of sand in suspension, and looseness of producing bed and tendency to cave.

When dealing with wells which give up their oil with difficulty, it is advantageous to instal a rotary gas pump (vacuum pump). The annulus between the water-string and the column of swabbing tubes is packed off at the top, and a connection made from this to the suction inlet of the vacuum pump. By this means all the gas is taken from the well, and it assists the swab to keep the producing sand under a vacuum.

As is the case with pumping and bailing wells, swabbing wells should receive individual attention to ascertain the speed and number of runs required to obtain maximum production.

Mr. H. G. Austin said the paper not only covered the subject of swabbing very completely, but also embodied practical hints which would prove of value to students when commencing their oil-field experience. He asked whether the American type of swab (check valve instead of ball valve), fitted with a regulator, had ever been used in Galicia, as this would apparently overcome all troubles consequent to the swab being overloaded or lowered into the oil at too great a speed.

Mr. L. W. Marrison asked what additional area of oil-bearing

stratum was rendered available by the introduction of swabbing to a well.

Mr. F. R. S. Henson asked if the derrick construction was modified in any way to take up the resultant force due to the inclination of the winding rope, as in the ordinary mine headgear, or were guy lines considered sufficient, if conical drums had ever been tried to give variable winding speed, and if flat wire ropes had ever been used to overcome the tendency of ropes of circular cross section to ride up the sides of the groove in the pulley wheels.

Mr. E. Clark suggested the use of a headwheel fitted with parallel flanges to overcome the creeping of the swabbing line.

Mr. M. Stern asked how the amount of oil to be lifted could be determined before swabbing has been carried on for some time. He suggested that in districts where a number of wells were spread over a small area it would be more economical to supply steam to the winding engines from one central boiler, and also asked if, where electrical energy was available, electric motors had proved more economical and easier to manipulate.

Mr. Albert Millar, in reply to the Chairman's question, said the American type of swab had been tried but had not given such satisfactory results as the Galician swab. The practice of fitting a check valve to the bottom of the swab cannot be recommended for the following reasons :—

Firstly, should there be only a small distance from the bottom of the casing-shoe to the bottom of the borehole, the swab is liable to strike bottom almost every run, resulting in the valve being damaged or even broken off ; secondly, when the swab strikes the oil column at high speed, a severe shock is imparted to the swab, which would tend to loosen the check valve referred to. Even when using the Galician type of swab, which is of very solid construction, the regulating nuts as well as the check nuts become loosened and require replacing from time to time.

In order to minimise the effect of the blow to the swab on striking the bottom, it is good practice to cut up a number of old swabbing rings and lower them on to the bottom of the borehole, forming a cushion which partly absorbs the shock. The only present means of assuring the swab not being lowered too deeply into the oil column, is to first measure the height to which it rises in the borehole and then to set the depth signals on the winding set accordingly.

Replying to Mr. L. W. Marrison's question regarding the additional area of oil-bearing strata rendered available, it is difficult to give precise figures, but there is no doubt the swab very greatly increase the production radius. Wells vary very con-

siderably according to the porosity of the oilsand, for instance: Well "A," by intensive swabbing, took all the oil from Well "B," giving 60 tons daily and situated 80 metres away, and considerably affected the production of Well "C," situated over 200 metres distant. It has been proved that intensively swabbed wells completely drained the surrounding area to the extent of several acres in a comparatively short space of time. One of the benefits of intensive swabbing is that large areas can be drained much more quickly and thoroughly than by any other means. The oilsand, however, must be of a structure to allow of intensive swabbing, or, in other words, suitable of being kept under a fairly high vacuum.

In answer to Mr. Henson, the construction of the derricks is not altered in any way for swabbing, but guy lines are fixed to the girders which carry the headwheel, and the girders are in turn securely bolted to the derrick crown. Conical winding drums have never been tried. Flat wire ropes have never been used and would not prove practical for various reasons. For instance: the rope in small diameter casings would not only become badly worn, but the casing would also suffer. Very few wells are quite straight, and the rope being constantly in contact with the casing would result in the casing being cut through. This very often happens even with round small-diameter wire rope, and for this reason it is always advisable to turn the swabbing casing slightly at regular intervals to spread the wear over a larger area.

Regarding Mr. Clark's suggestion that headwheels be constructed with parallel flanges to overcome the creeping of the swabbing line, the tendency to creep would be less than with the "V" groove, but the wear on the rope would certainly be increased by reason of the side to side travel of the rope and flange friction.

In reply to Mr. Stern's query as to determining the amount of oil to be lifted, it is not possible to ascertain this before swabbing has been carried out. When the well to be swabbed is situated among other producing wells, the average production of those wells can be taken as a basis. The usual practice is to put in a smaller size winding set to start with, and if this is not large enough to deal with the production, a larger set is installed and the small set kept as a stand-by. It is always advisable to use one or more large steam generating units wherever possible. If electric power is available, it is cheaper and the manipulation is easier, but if the oilfield happens to be situated where severe winters are experienced, a steam boiler must be installed to supply steam for heating the oil.

REVIEWS.

La Viscosité des Huiles Minerales par Cristian Leu.

We have received a pamphlet on the mixture law as applied to the viscosity of binary systems of lubricating oils by Cristian Leu, Chief Chemist of the Rumanian Arsenal. After discussing the work of previous investigators on the viscosity of binary systems and also the formulæ proposed by Batschienski, Kurnakow, Faust, Bingham, Lees, Dunstan, etc., he deduces the following law :—

$$\frac{P}{p}\left\{\frac{(a_1-a)(a_1+a_2)}{2(a-a_2)(a_1-a_2)}\right\}=e^x$$

Where a_1 and a_2 are constants for the components and a for the mixture p and P are volume percentages of the two components and x represents the degree of association, being unity in the case of unimolecular liquids. Seeing that in the case of mineral oils this condition is probably the case, a working formula has been considered :—

$$\frac{P}{p}\ \frac{(V-V^1)\ (V+v)}{2(V^1-v)\ (V-v)}=e$$

Where V = viscosity of the heavy oil
v = " " " lighter oil
V^1 = " " " mixture
p = percentage by volume of the light oil (v)
P = " " " " heavy oil (V)

Details are given of much experimental work by the author and of the technique of his procedure, but chiefly interesting is the very well marked agreement shown between the values calculated and determined for upwards of fifty mixtures of oil whose viscosities range from 2·52 to 100·9 degrees Engler. The mean difference between the values observed and deduced from the new formula amount to 0·1 per cent. A. E. D.

"Le Mazout." By E. Davin. A. D. Allard, Paris. 20 frs.

The author of this little work, a French naval engineer, is particularly qualified to discuss the technique of the testing and application of oil by virtue of his long connexion with the Navy and his work at Pechelbronn.

Amongst the chief questions with which he deals may be cited :—The criteria of oil, density, viscosity, flow of oil in pipe-lines, calorific value, recent oil-fuel installations in the Navy, conditions for the reception of oil in warships, analysis of crude oil for marine purposes, customs regulations, tanks, colloidal fuels, utilisation of petroleum residues, types of burners and explosion risks.

The book is extremely clearly written and is an admirable summary—although very concise—of the subject as it appeals to the marine engineer.

There is little to criticise, but one may take exception to the classification of naphthenes as aromatic hydrocarbons and to the statement that asphalt is a polymerisation product of terpenes. A. E. D.

"Petroleum Year Book." Edited by Sidney North. The Petroleum Press, Ltd. 10s. 6d. net.

This survey of the progress in Petroleum Technology and Finances for the year 1922 contains reviews on Production by Messrs. E. H. Cunningham-Craig and G. Howell; on the General Characteristics of Crude Oil; on

Refining by Mr. J. E. Hackford; on the Application of Petroleum by Engineer-Lieutenant Commander Addymen; on Lubricating Oil by Mr. H. Moore; on the Oil Industry of Great Britain by E. H. Cunningham-Craig and J. A. Green; on Oil Shales; on Storage and Distillation; on Particulars and Records of Oil Companies, together with sections on statistics and miscellaneous information.

On the commercial side there is a company register and a series of oilfield records, whilst a brief glossary of petroleum terms brings the Annual to a conclusion.

The volume is likely to be a useful desk companion for all interested in the mineral oil industry. A. E. D.

"Petroleum Production Methods." By John R. Suman. Gulf Publishing Company, Houstan, Texas.

The author in writing for the field man confines himself to technical matter other than geological and aims at a comprehensive view of current practice in the Southwestern and Californian fields of the United States. He subdivides his subject into eight chapters dealing with (1) drilling methods, (2) shutting off water, (3) production, (4) emulsions, (5) electric power, (6) pipe-lines, (7) tanks and (8) tables and useful information. Of these the first three chapters occupy approximately two-thirds of the book, that on drilling alone, covering 250 pages. He has drawn largely from bulletins of the Bureau of Mines and other official sources and from papers read before various American technical associations during recent years. Although, generally, a satisfactory method, it has certain limitations such as in discriminating between actual practice and obsolete or stillborn processes, in correlating practice in different fields and more particularly in obtaining a general idea of any department as a whole. As regards the latter point it may well be argued that the difficulty is not confined to compilation as a source of authorship, and in this particular case, with a book written manifestly for American readers, it is unfair to lay too great a stress on it.

Since the book has already reached its third edition we should have liked to see more attention given to dates, when quoting from other sources, otherwise such details as costs lose much of their value and each section might well be closed with an argument as to present trend of developments and the present relative importance of the various methods which have been described. References to "a year and a half ago" or "of recent growth" are sufficiently ambiguous to be annoying.

Apart from these limitations the choice of material for a book written on this basis is wide and the author has exercised his discretion, on the whole, wisely both as regards subject-matter and in the matter of condensation. Thus, in the chapter dealing with drilling methods, the modern rotary occupies first place whilst cable tool practice follows. Diamond drilling, as applied to oilfield work, is dealt with only after more general details including fire hazards, power equipment, a rather condensed abstract of R. B. Woodworth's paper on steel rigs, read before the American Inst. of Mining and Metallurgical Engineers, without the illustrations which made the original so interesting, and various other data. It is doubtless difficult to avoid occasionally omitting essentials when abstracting from lengthy articles and the author has not entirely steered clear of this pitfall. He says, *e.g.*, on page 81, that the Elliott Double Core Drill will be described in detail but, unless the accompanying Fig. 24 is to be taken as fully complying with this, we fear the details have become merged into some groups of asterisks which follow. Again (page 499), in reference to the construction of a submarine

pipe-line in Mexico we are informed that "the accompanying pictures make the process clear." They probably do in the original but not in this book.

On page 344 when discussing air-lift work the values for C in the equation for compressor capacity used by the Ingersoll-Rand Company, which should be expressed thus :—

$$Va = \frac{h}{C \log \frac{H + 34}{34}}$$

where Va = cubic feet free air per minute actual required to raise one gallon of water
h = total lift in feet
H = running submergence in feet
C = constant

are given as based on lift and best submergence but, actually, these have been replaced by more practical figures based on submergence, which, for convenience, are here given.

Submergence ..	75%	70%	65%	60%	55%	50%	45%	40%	35%
"C"	366	358	348	335	318	296	272	246	216

Typographical errors are not infrequent and illustrations might, with advantage, have been more numerous. Photographs have suffered in the process of reproduction to such an extent as to be of slight technical value.

Apart from the defects above described, which may all be classed as of a minor character, the book is to be commended as a painstaking effort to present the subject under the various sub-headings mentioned and deserves acknowledgment as a useful reference work both for the man in the field and the student.

T. G. M.